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CONCERNING $\frac{T_1 - T_0}{T_1}$; OR, THE LIMIT OF EFFICIENCY OF HEAT ENGINES.

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A thermodynamic heresy of latter days having denied that this classic fraction represents the maximum efficiency of all heat engines irrespective of the nature of the working substance employed, and, having spread itself unopposed far and wide over the land to the injury and confusion of those not well grounded in the first principles of thermodynamics, it has been thought not inopportune to examine the grounds on which the aforesaid heresy seeks to justify itself and to restate, as simply as possible, the reasons for the faith in the applicability of this *coefficient of work* to all possible heat engines.

From a paper first read to the American Association for the Advancement of Science, and afterwards published, in its "Proceedings," in the JOURNAL OF THE FRANKLIN INSTITUTE, and also in part

and substance in the *Int. Sci. Series* and *Pop. Sci. Monthly*,* we glean the following:

(1) The present type of vapor engines, represented by the steam engine, has an efficiency, theoretically attainable, which is *greater* than $\frac{T_1 - T_0}{T_1}$.

(2) Gas engines have been frequently designed and built whose theoretical efficiency was *unity*.

(3) It is theoretically possible to have a "new type of steam engine" which will produce work without rejecting any heat.

These three forms of grievous error characterize the heresy and shall be destroyed, root and branch, in the latter parts of this paper, the earlier parts being devoted to demonstrating anew the principles underlying the efficiency of all heat engines. These principles, expressed in the form of propositions, are as follows:

Proposition A.—It is impossible for any heat engine to perform work by the expansion and contraction of the volume of its working substance without rejecting heat.

Proposition B.—The efficiency of a reversible engine, which receives and discharges heat only at its upper and lower limits of temperature respectively, is *not less* than that of any other engine having the same range of temperature.

Corollary 1.—A reversible engine which receives and discharges heat only at its upper and lower limits of temperature respectively is an engine of maximum efficiency for its range of temperature.

Corollary 2.—A reversible engine which not only receives and discharges heat at its upper and lower limits of temperature respectively, but also receives and discharges heat at intermediate temperatures in such a way that the amounts received and rejected at any given temperature are always equal, is an engine of maximum efficiency for its range of temperature.

Corollary 3.—Tne maximum efficiency of one kind of reversible heat engine is equal to that of any other having the same range of temperature; or

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*See Proc. Am. Ass. for the Adv. of Science, 1877, JOURNAL FRANK. INST., Vol. CIV., pages 252, 325, 389—Growth of the Steam Engine. *Int. Sci. Series*, 1878.—Growth of the Steam Engine, *Pop. Sci. Monthly*, 1878. All by Prof. R. H. Thurston. See also "Theoretical Steam Engine," by Chas. E. Emery, *Sci. Am. Supp.*, July 18, 1877.

The maximum efficiency of an engine is independent of the nature of the working substance employed, and is simply a function of the two limits of temperature between which the engine works.

Proposition C.—Other things being equal, a reversible engine is more efficient than an irreversible one.

Proposition D.—The maximum efficiency of any heat engine is represented by the proper fraction $\frac{T_1 - T_0}{T_1}$, T_1 and T_0 being respectively the highest and lowest absolute temperatures attainable by the working fluid in the engine.

At this point we may be allowed to call attention to the incomplete treatment given to this matter of efficiency in the elementary treatises on heat. Corollary 3 is generally mentioned, sometimes proved for a particular case. Propositions A and B are either tacitly assumed as self-evident, or only Proposition B demonstrated for the common case when there are but two reservoirs of heat (boiler and condenser). The efficiency of engines having "regenerators"* is generally ignored, the reason probably being that the use of more than two reservoirs renders the demonstration somewhat more complicated. Proposition C is often assumed to be identical with a particular case of proposition B: we ourselves have not been able to demonstrate it rigidly without recourse to the calculus. Proposition D is easily obtained from the preceding propositions and the sample formulæ of proposition C. In the more advanced treatises on heat—those by Rankine, Hirn, Zeuner and McCulloch—all the above principles follow readily from equations established by the aid of the calculus. To those not familiar with this branch of mathematics, such deductions are not perfectly satisfactory, and to this class of readers it is hoped most of the demonstrations given will not be without value.

Before demonstrating the above propositions, we will first define what is meant by a *cycle* in thermodynamics and then not only describe the cycles belonging to the two theoretically perfect engines, but also describe the cycle belonging to the more general and imperfect case. Definitions of reversibility and efficiency of engines will also be given, and the general method of demonstration indicated.

* This term is applied in air engines to a mass of metal plates or network of wires which serve to absorb the heat of the charge of air as it is leaving the working cylinder of the engine and give it up again to the new charge of air while on its way to receive a new supply of heat from the furnace.

The simple and fruitful conception of a *cycle* we owe to Carnot. It consists in supposing a body which has experienced a certain number of transformations to be brought back to identically the physical state as to density, temperature and molecular constitution which it possessed at the beginning of the series of changes. The initial and final states of the body being the same, its *internal energy* at the beginning and end of the cycle will be the same, and any mechanical effects that may have been produced during the complete cycle of operation can only be ascribed to purely external thermal changes. A cycle can be represented graphically by a series of lines forming a closed curve, as *a*, *b*, *d*, *c*, *a*, (Fig. 1). When the coördinates of the diagram are volumes and pressures, a cycle may also be called an indicator diagram, because it represents not only the changes of pressure and volume experienced by the body, but also the work done by the latter.

The simplest of the two perfect engines is that which describes an indicator diagram called "Carnot's cycle," which consists of "four operations" represented by the four curves, *ab*, *bc*, *cd*, *da* (Fig. 1). We will describe the four operations: Suppose a body in the cylinder of an engine to have a volume *om* and pressure *ma*, and that the temperature corresponding to this volume and pressure is t_1; if the body is now placed in communication with a source of heat, *M*, at the same (or insensibly higher) temperature t_1, and be allowed to expand so that its temperature remains constantly equal to that of the source *M*, it will perform the external work *mabr*, and will receive an amount of heat from *M* represented by Q_1. This ends the first operation, which is sometimes briefly described by saying the body receives heat along an isothermal *ab*. During the second operation the source of heat *M* is supposed to be removed and the body to expand without transmission of heat in the non-conducting cylinder till its temperature has fallen to that of the refrigerator *N*, namely, t_0; the body will then have again done work represented by *rbcs*, but without any transmission of heat to or from external bodies. This operation is also described thus: The body expands along the adiabatic curve *bc*. In the third operation the body is supposed to be in contact with the refrigerator *N*, and is then compressed by means of a piston so that its temperature remains constantly equal to that of *N*. The work expended on the body will then be equal to *cdns*, and the heat withdrawn from the body may be represented by Q_0, which is always less than Q_1. The compression is continued till the body reaches a state

d, from which, by means of the fourth operation, consisting of compression without thermal communication with external bodies, the body may be brought back to its original, primitive state *a*. The work expended in the body along the adiabatic *da* will be *damn*, and the last two operations are often briefly described as compression along the isothermal *cd* and adiabatic *da*. During this cycle of operations a quantity of heat $Q_1 - Q_0$ has been transformed into the work $W = J(Q_1 - Q_0)$=area *abcd*, and contemporaneously a quantity of heat Q_0 has been transferred from the hot body *M* to the cold body *N*. This is a point that has not received in elementary treatises on heat the attention that it deserved; this quantity of transmitted heat Q_0 stands in just as definnite and persistent a relation to the work performed as the transformed heat $Q_1 - Q_0$. It cannot be too strongly insisted upon that whenever, in a cyclical process, mechanical effect is produced we always have not only a *disappearance* of heat equal to the work performed, but a *transmission* of heat from a hot body to a cold body. This being true, the working fluids which actuate our heat engines, must also serve as mediums for the transmission of heat, and must, therefore, not only *receive* heat, but *reject* heat. Carnot, endeavoring to explain *how* work was obtained from heat, called attention to the fact that the performance of work in steam and air engines was always accompanied by a transmission of heat. His assumption of the Caloric theory, however, led him into the error of supposing that all heat received would be rejected; that, as much heat would be found in the condenser as had been received by the boiler, and, therefore, that the performance of work was due to the *mere transmission* of heat. We now know that this was only an approximation to the truth, that of the heat received by the working substance a part is transformed into work and the remainder transmitted to a colder body.

Before demonstrating the correctness of this assertion, we will call attention to another of Carnot's fruitful conceptions: The reversible cycle, which consists in supposing the working substance employed in the theoretical engine to pass through such a series of transformations that the physical, chemical and mechanical changes that may accompany or cause them can take place in the opposite sense when the engine is reversed; then, if while the engine is running forward, the result of the cycle of operations *abcda* is the production of an amount of work *W*, the disappearance of a quantity of heat $Q_1 - Q_0$, and the transmission of the heat Q_0 from the source *M* to the refrige-

rator N, the result of the reversed cycle *adcba* will be the *expenditure* of an equal amount of work W, the *generation* of an equal quantity of heat $Q_1 - Q_0$ and the transmission of the heat Q_0 from the cold body N to the hot body M. For, when the cycle is reversed, the working substance receives back from its former refrigerator N an amount of heat Q_0 equal to that discharged into N during the first or forward set of operations and gives up to the source M a quantity of heat Q_1 equal to that previously received. This conception of reversibility is a purely ideal one and can never be realized completely by an actual engine, for it requires that the temperature of the working substance should not be sensibly different from those of the external bodies with which it is brought into thermal communication, and that its expansive force should not be sensibly different from the external pressure to which it is opposed.

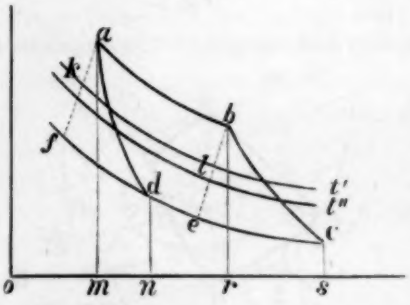
Carnot's cycle, which we have been hitherto considering, is of great interest because it represents the simplest perfect engine; in it only two reservoirs of heat—the source M and the refrigerator N—are in thermal communication with the working substance, and keep the latter at constant temperature while transfer of heat is taking place, the necessary fall and rise of temperature being respectively accomplished by the expansion and contraction of the volume without any *thermal* communication with external bodies. In graphical thermodynamics this is briefly expressed by saying that Carnot's cycle is composed of two isothermal and two adiabatic curves.

There are, however, an infinite number of cycles or diagrams composed of only four curves, which also represent theoretically perfect engines. Two, *ab* and *ef* (Fig. 1), of these four curves, as in "Carnot's cycle," are isothermals; the other two, *be* and *af*, are called by Rankine *isodiabatics*, and represent the changes of volume and pressure of the working fluid when respectively discharging and receiving heat at temperatures lying between the extremes. They are always found in pairs, being inseparably connected by the condition that the heat discharged by the fluid at one temperature must be exactly equal to that received by it when at the same temperature, or, referring to the diagram, this condition may be expressed by saying that the heat discharged along the element l, lying between the isothermals t' and t'', must be exactly equal to that received along k. But, in order that this condition may be fulfilled and the series of changes represented by *be* and *af* be reversible, more than two reservoirs of

heat are needed—an indefinite number, in fact—one for each temperature. One reservoir may then be made to do duty both as a source and as a refrigerator, receiving as much as it imparts and having at the end of the operation as much heat as at the beginning. In such a cycle the heat expended and rejected will (as in Carnot's cycle) be that which is furnished and abstracted by the reservoirs M and N along the isothermals *ab* and *ef*. We will hereafter prove that the efficiency of an engine having the indicator diagram *abef* is equal to that describing Carnot's cycle, or diagram *abcd*.*

The two cycles hitherto described have been chosen because of their simplicity and because they represent the only two classes of engines whose efficiency is equal to the maximum.

Fig. 1.



As may be easily imagined, there are an infinite number of others whose working fluids receive and discharge heat at temperatures lying between the available extremes, without necessarily receiving and discharging equal amounts, and which have numerous reservoirs not necessarily at the same temperature as the working substance during the transfer of heat. The indicator diagram, *abcda* (Fig. 2), may be taken as the representative of such an engine. In this case, as in every other, the efficiency is measured by the ratio

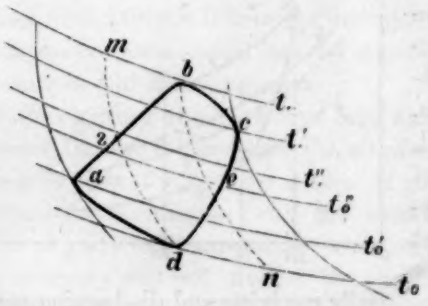
$$\frac{W}{JQ_1} = \frac{\text{Work done}}{\text{Heat expended (ft. lbs.)}} \qquad (1)$$

In the simple cycle, *abcda* (Fig. 1), the heat expended is identical with the total heat received by the working substance, and the heat permanently rejected with the total amount abstracted; but in *abefa* (Fig. 1) we no longer find this to be the case, the heat expended and

* One of the isodiabatic curves may be arbitrarily assumed and the other obtained by combining the above condition with the equation expressing the relation betweeen the volume, pressure and temperature of the working fluid employed. The adiabatics are only a particular case of the iso-diabatics; that, namely, in which the transmission of heat equals zero, and since the former are often and properly called *curves of no transmission of heat*, the latter may, in the above limited sense, be called *curves of equal transmission of heat.*

rejected being respectively equal to the heat lost by the reservoir at the highest temperature and that gained by the reservoir at the lowest temperature, the losses of all the intermediate ones being balanced by their gains. In the general case represented by *abcda* (Fig. 2) we must in like manner be careful to distinguish between the heat expended and the total heat received by the working substance, also between the total amount of heat abstracted and that part of it which is rejected, never to be again used in subsequent cycles. Since we are here seeking to determine the conditions of maximum efficiency, we will suppose our engines to run without friction, that there are no leakages of heat due to imperfect protection against induction and radiation, and that no losses occur which are due to permanently rejecting heat capable of partially or completely compensating the intermediate reservoirs for their losses of heat. Assuming that all these sources of loss have been removed, we can now define the quantity of heat expended in a cyclical process to be that quantity which is equivalent to the work done plus the heat permanently rejected; expressed analytically, this is

Fig. 2.



$$J\,Q_1 = W + J\,Q_0 \qquad (2)$$

which can also be written

$$W = J\,(Q_1 - Q_0) \qquad (3)$$

where J represents the mechanical equivalent of heat, and Eq. (3) the law of the equivalence of heat and work when applied to cyclical processes. This will perhaps be more evident if we introduce into Eq. (3) the terms which have disappeared because of theabove-mentioned compensation; then

$$W = J\,[Q_1 + q - (q + Q_0)] \qquad (4)$$

when $Q_1 + q$ represent the total amount of heat received, and $q + Q_0$ the total amount rejected by the working substance.

In demonstrating the propositions given at the beginning of this article we shall only make use of two principles, which, though simple, are the foundation of the whole Science of Heat. They are

I. "When work is transformed into heat, or heat into work, the quantity of work is mechanically equivalent to the quantity of heat."

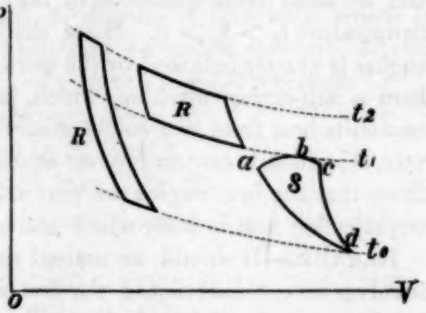
II. "It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature."*

These two principles are sometimes called the first and second laws of thermodynamics; in the form here given they are simply "the condensed expression of experimental facts."

Proposition A.—*It is impossible for any heat engine to perform work by the expansion and contraction of the volume of its working substance without rejecting heat.*

Let S (Fig. 3) represent the indicator diagram† of an engine which rejects no heat and yet performs work, its range of temperature being t_1, t_0. In like manner, let R be the diagram of a reversible engine which receives all its heat at the temperature $t_2 > t_1$ and rejects heat at any temperatures equal to or less than t_1. Let K be the source from which R draws its heat, N the reservoir or refrigerator into which it discharges heat, and M the source or sources of heat for S, with temperature equal or less than t_1. When both R and S are performing work, let the work produced by R be equal to that produced by S; then

Fig. 3.



W_1 = work performed by engine R
W_1^1 = " " " S
Q_1 = heat furnished to engine R by K
Q_1^1 = " " " S " M
Q_0 = heat abstracted from engine R by N

When engine R is reversed we have

* This principle was first enunciated by Clausius in this slightly different form, "Heat cannot, of itself, pass from a colder to a warmer body."

† The diagrams used in all the demonstrations are for the purposes of illustration and abbreviation, not for graphical demonstration.

W_1 = work expended on engine R
Q_0 = heat furnished to " " by N
Q_1 = " abstracted from " " " K

In either case the values of Q_1, Q_0 and W_1 are the same, and we have from our first principle:

$$W_1 = J(Q_1 - Q_0)$$

and if S can perform work without rejecting heat

$$W_1^1 = J\,Q_1^1$$

and since $$W_1 = W_1^1 = J(Q_1 - Q_0) = J\,Q_1^1$$

we have $$Q_1 = Q_0 + Q_1^1$$

Now suppose the two engines to be so combined that S will drive R backward, the latter will then transform the work expended on it into the heat Q_1^1, and will also abstract the heat Q_0 from the refrigerator N and transmit both quantities of heat Q_1 to the reservoir K at the temperature $t_2 > t_1 > t_0$. Since the work expended in running one engine is exactly balanced by the work developed in the other, we have here a self-acting machine, which, unaided by any external agency, transmits heat from two colder reservoirs, M and N, to a hotter reservoir, K, which is contrary to our second principle; therefore the hypothesis that any heat engine can perform work in a cyclical process without rejecting heat is false, which was to be proved.

REMARK.—It should be noticed that the result of the combination involves no contradiction of the first principle; for the heat Q_1 gained by the reservoir K is exactly equal to the heat $Q_0 + Q_1^1$ lost by the reservoirs N and M.

Proposition B.—*The efficiency of a reversible engine which receives and rejects heat only at its upper and lower limits of temperature, respectively, is* NOT LESS *than that of any other engine having the same range of temperature.*

Let the reversible engine, which receives and discharges heat at the highest and lowest temperatures, t_1, t_0, respectively, be represented by R, and have for its indicator diagram *mbnd* (Fig. 2), and let any other engine having the same range of temperature be represented by S, and have an indicator diagram of any form, as *abcda* (Fig. 2), but included between the isothermals t_1 an t_0.

Suppose that besides the two reservoirs of heat (M and N), at the highest lowest temperatures (t_1, t_0, respectively) there are an indefinite number of intermediate reservoirs (M_1^1, M_1'' . . . . N_0^1) which while transferring heat may or may not be at the same temperature as the

working substance, according as the cycle *abcda* is reversible or irreversible. Now suppose both engines to perform work, and that

w = work performed by engine R
W = " " S
q_1 = heat received by R from M
q_0 = " abstracted from R by N
$Q_1 + Q$ = total heat received by S from M, $M_1^1 \ldots . N_0^1$
$Q_0 + Q$ = " abstracted from S by N, $N_0 \ldots . M_1^1$
Q_1 = heat expended in driving S
Q_0 = " permanently rejected by S
Q = " not " " "
= " returned to $M_1^1 \ldots . N_0^1$

When the engine R is reversed it no longer performs but consumes work, transforming that expended in driving it into heat, which it delivers to M; it also abstracts heat from the coldest reservoir, N, and delivers it to the hottest reservoir, M; in this case (R reversed)

w = work expended in driving R
q_0 = heat received by R from N
q_1 = " abstracted from R by M

In either case the values of w, q_1 and q_0 are the same, and we have from our first principle

$w = J(q_1 - q_0)$ and $W = J[Q_1 + Q - (Q + Q_0)] = J(Q_1 - Q_0)$

Now if it be denied that the efficiency of R is *not less* than that of S, we must have

$$\frac{w}{Jq_1} < \frac{W}{JQ_1}$$

This, we will show, leads to a contradiction of our second principle; for suppose the work that can be performed by the reversible engine R to be exactly equal to that performed by S, then if the two engines are coupled together so that S drives R backward, the whole work performed by S will be expended in driving R and will be transformed in the working substance of the latter into heat, which is finally delivered to the hottest reservoir, M. Besides transforming work into heat, the engine R abstracts heat equal to q_0 from the coldest reservoir, N, and transfers it to the hottest reservoir, M. The total amount of heat delivered by R to M will then be

$$q_1 = \frac{W}{J} + q_0 = Q_1 - Q_0 + q_0$$

There is a part (Q_0) of the total heat abstracted ($Q_0 + Q$) from the working substance of S, which must be regarded as permanently rejected by the engine because it cannot assist in diminishing the expenditure of heat in subsequent cycles equal and similar to *abcda*. Now suppose that after the engine S has completed its cycle, the permanently rejected heat (Q_0) be allowed to flow, by *conduction or radiation* into the coldest reservoir, N, and that the remaining part, Q, of the total heat abstracted be also allowed to flow by *conduction or radiation* into these reservoirs (M_1^1 M_1'' . . . . N^1_0) of intermediate temperature, which have lost heat by supplying it to the working fluid of the engine S. If this compensating process be so conducted that the restoration of heat takes place between reservoirs as nearly as possible of the same temperature, the heat restored (Q) will be a maximum for the given cycle *abcda*, and the heat permanently rejected (Q_0) a minimum. The final result of this procedure is that at the end of the cycle *abcda* every reservoir in thermal communication with the working substance of the engine S, except the coldest one (N), will either be in the same condition that it was originally, or will have lost heat. Only the coldest reservoir (N) will have gained heat, and this only to the extent (Q_0) — the minimum amount of permanently rejected heat.

It will be remembered that in consequence of the denial of our present proposition we obtained

$$\frac{w}{Jq_1} < \frac{W}{JQ_1}$$

If we combine this inequality with the equation

$$w = W = J(q_1 - q_0) = J(Q_1 - Q_0)$$

we get

$$Q_1 < q_1 \text{ and } Q_0 < q_0$$

That is, the heat gained (Q_0) by the coldest reservoir (N) is less than the heat (q_0) which it loses, the difference ($Q_0 - q_0$) having been transferred to the hottest reservoir (M). The losses suffered by the various reservoirs of S will then be

$$Q_1 - Q_0 + q_0$$

and the gain experienced by M,

$$q_1$$

The preceding equation shows us that these two expressions are exactly equal; there has, therefore, been no destruction or creation of heat energy, which is in accordance with our first principle. But in our combination of engines the work expended is exactly equal to that

produced, and we have here, therefore, a self-acting machine which, unaided by external agency, is capable of transferring heat from the colder bodies M_1', M_1'', ... N to the hotter body M, which is contrary to our second principle, "Heat cannot, of itself, pass from a colder to a warmer body." Therefore the supposition that

$$\frac{w}{Jq_1} < \frac{W}{JQ_1}$$

is false, which was to be proved.

REMARK.—It should be noticed that the foregoing demonstration is applicable whether S be a reversible or irreversible engine, for only R is reversed.

Corollary.—*A reversible engine which receives and discharges heat only at its upper and lower limits of temperature, respectively, is an engine of maximum efficiency for its range of temperature.*

This corollary is an immediate consequence of the proposition just demonstrated, for since the efficiency of R is not less than the most efficient of all the possible engines represented by S, it must be equal or greater, and R is therefore an engine of maximum efficiency for the given range of temperature.

Corollary 2.—*A reversible engine which not only receives and discharges heat at its upper and lower limits of temperature, respectively, but also receives and discharges heat at intermediate temperatures in such a way that the amounts received and rejected at any given temperature are always equal, is an engine of maximum efficiency for its range of temperature.*

It will only be necessary to prove that the efficiency of the reversible engine contemplated by the present corollary, and which we will call S^1, is equal to that of R, which has just been shown to be an engine of maximum efficiency for its range of temperature.

Since S^1 is only a particular case of the general engine S of proposition B, it follows from that proposition that the efficiency of S^1 cannot be greater than that of R, and we have now only to prove that S^1 cannot be less than R.

Suppose S^1 is less than R, then we must have:

$$\frac{W_1^1}{J\,Q_1^1} < \frac{w}{Jq_1}$$

Now let R be so chosen that it will perform the same amount of work as S^1, and then couple the two together so that the one supposed

to be most efficient will drive the other backward, *i. e.*, R drives; then, by reasoning exactly like that of proposition B, we can show that the quantity of heat in the intermediate reservoirs of S^1 will be the same at the end of the cycle as at the beginning, and that the only change that has taken place is the transfer of heat from the coldest reservoir N to the hottest M by a self-acting machine unaided by external agency, which is contrary to the second principle and consequently the supposition that the efficiency of S^1 can be less than that of R is false, and since it is not greater, we must conclude that the efficiency of S^1 is equal to that of R, in other words, S^1 is an engine of maximum efficiency for its range of temperature, which was to be proved.

Corollary 3.—*The maximum efficiency of one kind of reversible heat engine is equal to that of any other having the same range of temperature; or,*

The maximum efficiency of an engine is independent of the nature of the working substance employed, and is simply a function of the two limits of temperature between which the engine works.

The previous propositions and corollaries apply equally well to all heat engines whatever, for they contain no limiting conditions which would restrict them to any particular working substance. It has been thought desirable, however, to emphasize this point in the present corollary. Here, therefore, different kinds of heat engines must be understood as meaning engines differing only in the working substances driving them, moreover the maximum efficiency of one kind of heat engine must, in accordance with corollary 1, be understood to mean the efficiency of that kind of engine when receiving and discharging heat only at its upper and lower limits of temperature; thus understood, the two forms of this corollary become equivalent, and one demonstration will answer for both. If either be denied, it will follow that the maximum efficiency is not constant, being greater for certain kinds of heat engines than for others; it will then be easy to show by methods precisely analogous to those already employed that a result will be arrived at contrary to the oft-quoted second principle.

Proposition C.—*Other things being equal, a reversible engine is more efficient than an irreversible one.*

It will be remembered that an engine was defined as irreversible when the temperature of its working substance differed sensibly from that of the external bodies with which it was brought into thermal

communication, or when the expansive force differed sensibly from the external and opposing force.

When the first of these conditions of irreversibility only is present, it is easy to show by the foregoing methods that, other things being equal, a reversible engine is always more efficient than an irreversible one; but when the latter condition is present these methods are no longer applicable, for there is then either friction among the particles of the working substance or sensible motion, either of which will produce heat, but the influence of which on the efficiency it is not easy to ascertain without recourse to analytical methods. Before employing these, however, we will say that generally in an irreversible engine the external opposing force is less during expansion and greater during compression than the expansive force of the working substance; the external work performed in an irreversible engine, for a given quantity of heat expended, will therefore be less than if these opposing forces were equal as in the reversible engine.

The formulæ which are to aid us in demonstrating the present and following propositions, are those which are now well established as the analytical expressions of the two fundamental laws of the mechanical theory of heat when applied to cyclical processes. They are:

$$\text{I. } W = J \Sigma Q \qquad \text{II. } \int \frac{dQ}{T} \leqq 0$$

Where

W = work done during a cycle
$+Q$ = heat received by working fluid
$-Q$ = heat abstracted from working fluid
$+dQ$ = increment of heat at absolute temperature T
$-dQ$ = decrement of heat at absolute temperature T

In expression II. the sign of inequality belongs to irreversible cycles, and that of equality to reversible ones; the integral sign extends over all those portions of the cyclical process at which heat is received or abstracted by the working fluid. Then, if as before we let

Q_1 = heat permanently expended.
q = heat received and restored.
Q_0 = heat permanently discharged.
T_1, T_0 = absolute temperatures corresponding to Q_1 and Q_0
τ_1, τ_0 = absolute temperatures of q when respectively received and restored.

Expressions I. and II. will then become:

$$W = J(Q_1 + q - q - Q_0) = J(Q_1 - Q_0) \quad \text{I.}^1$$

$$\int \frac{dQ_1}{T_1} + \int \frac{dq}{\tau_1} - \int \frac{dq}{\tau_0} - \int \frac{dQ_0}{T_0} \leq 0 \quad \text{II.}^1$$

Equation I.[1] shows us that for a given quantity Q_1 of heat expended W will be a maximum when Q_0 is a minimum. From formula II.[1] we can determine one of the conditions which will make Q_0 a minimum, for, transposing, we have

$$\int \frac{dQ_0}{T_0} \geq \int \frac{dQ_1}{T_1} + \int \frac{dq}{\tau_1} - \int \frac{dq}{\tau_0} \quad \text{II}^1.$$

This equation shows us that other things being equal, Q_0 will be least (and consequently the efficiency greatest) when the sign of equality is employed, *i. e.*, when the process is a reversible one, which was to be proved.

Proposition D.—*The maximum efficiency of any heat engine is represented by the proper fraction*

$$\frac{T_1 - T_0}{T_1}$$

T_1 and T_0 being respectively the highest and lowest absolute temperatures attainable by the working fluid in the engine.

It was established in corollary 1 that when $q = 0$ and Q_1, Q_0 are respectively received and discharged at the highest and lowest attainable temperatures, the efficiency of the engine would be a maximum. From corollary 2 we have that when $\tau_1 = \tau_0$ and Q_1, Q_0, are respectively received and discharged at the highest and lowest attainable temperatures, the efficiency of the engine is also a maximum. Introducing either of these sets of conditions of maximum efficiency into *Equation* II. we get

$$\frac{Q_0}{T_0} = \frac{Q_1}{T_1} \quad \text{II.}^{11}$$

substituting for Q_0 in Equation I. its value obtained from Equation II.[11], and reducing we get

$$\frac{W}{JQ_1} = \frac{T_1 - T_0}{T_1} \quad \text{III.}$$

Where $\frac{W}{JQ_1}$ equals the maximum efficiency of any kind of heat engine, and T_1, T_0 equal the highest and lowest absolute temperatures attainable by the working fluid in the engine. *Q. E. D.*

(To be continued.)

BOILER EXPERIMENTS.

An account of some experiments made in 1873, *at the Washington Navy Yard, on the* 8 *feet diameter cylindrical boiler used with compound engines in several steamers of the United States Navy.*

By Chief Engineer ISHERWOOD, U. S. Navy.

As it is necessary in war steamers that the entire machinery be placed below their water line, the height of their boilers in small vessels is, consequently, greatly restricted, and, in many such vessels of the United States Navy, 8 feet were all that could be obtained. When the boilers were to furnish high pressure steam for a compound engine, their shells had to be cylindrical and of this diameter, and it was difficult in so small a circle to obtain a satisfactory arrangement of the furnace and tubes. The plan of boiler finally adopted, is the one shown in the sketch accompanying this paper, and three experiments were made with it at the Washington Navy Yard by Chief Engineers Loring and Baker, of the United States Navy, to determine the effect upon its absolute and economic vaporizations produced by the two modifications of the tube surface and calorimeter hereinafter described. These experiments are the only ones ever made on the evaporative efficiency of boilers of this type with the given proportions, and as several steamers of the United States Navy are fitted with them, it is of interest, in view of a comparison of the cost of the horse-power developed by their engines in pounds of coal consumed per hour, to know the weight of water vaporized per pound of coal.

An important practical evil of boilers of this small diameter at once developed when they were put in use, namely an incorrigible tendency to "prime" or "foam," which required the throttle valve to be nearly always carried very much closed; and, when only a portion of the boilers of a vessel were employed, the smaller that portion, the closer had the throttle to be closed. A very high pressure was thus required in the boiler to furnish a very moderate one in the cylinder, involving all the undoubted disadvantages of high pressure steam, while none of its presumed advantages could be obtained. The excessive strain on the boiler and the excessive temperature in the fire-room, produced by the high pressure steam, were fully realized; but neither the supposed

benefit of a large measure of expansion for this very high pressure could be had, nor the unquestionable benefit of a relatively small back pressure against the piston, due to a high average total pressure upon it during its stroke.

The tubes were secured in the tube-plates by means of screw ferrules of brass $1\frac{1}{2}$ inches long, on the outer circumference of which a thread was cut fitting into a corresponding thread cut on the inner circumference of the tube. The ferrule at the back end of the tube had a shoulder which fitted against the outside of the tube-plate, the end of the tube fitting against the inside and forming a shoulder there, so that when the ferrule was turned by means of a wrench on the outside, the shoulders of the ferrule and of the tube were compressed against the tube-plate. The ferrule at the front end of the tube, for the thickness of the tube-plate, had a diameter greater than the outside diameter of the tube, and on the circumference of this greater diameter a thread was cut fitting into a corresponding thread cut in the tube-plate: by means of these threads the ferrule was screwed into the tube-plate, while simultaneously it was screwed into the tube by means of the threads previously described cut on the inner circumference of the tube and on the outer circumference of the ferrule where its diameter was least. By unscrewing the ferrules at both ends of a tube, the latter could be drawn out without injury for examination or cleaning; or for convenience in examining, cleaning or repairing the inside of the boiler shell. This was the purpose of the design which, however, signally failed in the application, as after a short subjection to the high temperature of the gases of combustion, the fittings were so warped and altered that the screws became inoperative, and the removal of the tubes involved the destruction of both them and the ferrules. This very expensive, useless and *un*practical method of securing the tubes in their plates, was originally a French invention and had been tried in the boilers of several French steamers, but its use had long been discontinued before its application to the boilers of any United States Naval steamer.

As regards the experiments, it is regrettable that they were not continued for a longer time than twelve hours each, which is far shorter than desirable for reliable results, although, in their cases, great accuracy of observation was depended on to obviate this objection. That the boiler was not protected with the usual non-conducting covering, is

also to be regretted, though the writer has been able to satisfactorily supply the deficiency from other data.

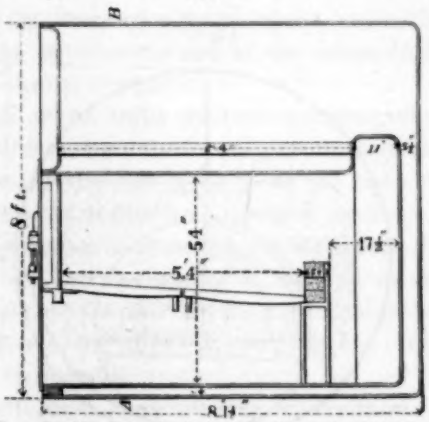
The original notes of these experiments were furnished by Chief Engineer Baker to the writer, who has made the necessary calculations from them, and arranged both data and results in a tabular form, prefacing the table with a description of the boiler and of the manner of making the experiments, and following it with some remarks.

Boiler.

The boiler is of the horizontal fire-tube type with nearly all the tubes returned by the sides of the furnace. It is a duplicate of many in use with compound engines on board of U. S. Naval steamers of a small size.

The shell of the boiler is a cylinder of 8 feet diameter and 8 feet 1 inch length, with flat ends. The back end is flush with the end ofthe shell, but the front end is recessed $4\frac{1}{2}$ inches within the shell. The entire shell is constructed of $\frac{5}{8}$ths inch thick plate iron, with the joints butted, single welted, and double riveted. The front end serves for the front tube-plate.

Fig. 1.



Longitudinal vertical section through axis of shell, exclusive of uptake.

The shell contains a single cylindrical furnace of 54 inches inner diameter and 6 feet $8\frac{1}{2}$ inches extreme length. It contains a grate 4 feet 6 inches wide and 5 feet 4 inches long. The grate-bars are of the ordinary pattern, and are cast in two equal lengths. The grate surface, at the front, coincides with the horizontal diameter of the furnace, sloping downwards 4 inches at the back. The bridge-wall is of cast iron, faced with fire-brick $4\frac{1}{2}$ inches thick on the 9 inches it rises above the back of the grate. The bottom of the ash-pit is $4\frac{1}{2}$ inches above the bottom of the shell. The furnace is constructed of $\frac{1}{2}$ inch thick iron in three equal lengths, and has, at each end of the middle length, a stiffening

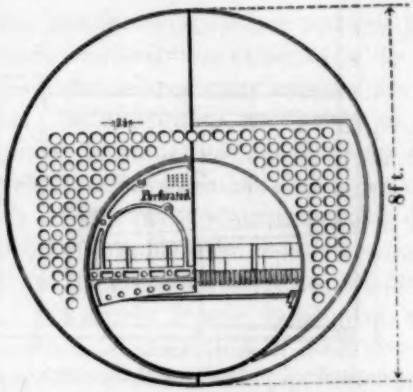
ring inserted of iron $2\frac{1}{2}$ inches deep, $\frac{1}{2}$ inch thick, and 5 feet outside diameter.

The furnace has two doors placed side by side; each door-opening is semi-circular on top, 20 inches wide and 16 inches high. Each door is perforated with eleven holes of $1\frac{3}{8}$ inches diameter for the admission of air; and the lining plate is perforated with as many $\frac{1}{4}$ inch diameter holes as it will contain, for the distribution of this air above the incandescent coal.

The front of the furnace is of cast iron with a double shell; the outer shell is pierced with seventeen holes of $1\frac{3}{8}$ inches diameter for the admission of air; and the inner shell is pierced with as many $\frac{1}{4}$ inch diameter holes as it will contain, for the distribution of this air above the incandescent coal.

The back smoke connection is 11 inches wide in the clear lengthwise the boiler: it is flat on top, with its sides and bottom concentric with

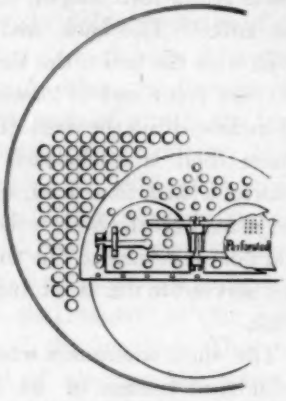
Fig 2.



Half elevation, with uptake and outer plate of furnace front removed.

Half cross section on *A B*, Fig. 1.

Fig 3.



Front elevotion, exclusive of uptake.

the cylindrical shell of the boiler from which they are separated by a water-space $4\frac{1}{2}$ inches wide including thicknesses of metal. The sides and bottom are, consequently, a segment of a circle 7 feet 3 inches in diameter. The extreme height of the connection in the clear is 5 feet 3 inches. The back of the connection is flat and parallel to the end of the boiler shell from which it is separated by a water-space $5\frac{1}{2}$ inches wide including thicknesses of metal. The connection is stayed to the

boiler shell by socket bolts of one inch diameter spaced every 6 inches. The whole of the connection is of plate iron $\frac{5}{8}$ths of an inch thick.

The tubes, with the exception of those of the upper row, twenty-one in number, are divided into two equal and symmetrical groups, one of which is returned on each side of the furnace from the back smoke connection to the uptake, completely filling the spandrels between the furnace and the boiler shell. Of these tubes, sixteen (eight on each end) lie below the level of the top of the bridge-wall, and six (three on each side) lie just at the level of that top, The upper row of tubes lie unbroken above the furnace.

The tubes are of brass and seamless, and are secured to their plates by screw ferrules of 2 inches inside diameter. Each tube is $2\frac{1}{2}$ inches 2·3 inches in inside diameter, in outside diameter and 6 feet 4 inches in extreme length to outside of tube-plates. They are one hundred and nineteen in number. The object of the screw ferrules was to allow the tubes to be removed for cleaning without injury, and to be replaced quickly. The distance between the axes of the tubes, horizontally, is $3\frac{1}{2}$ inches; and, vertically, 3·2 inches.

Above the tubes, the flat ends of the boiler shell are stayed together by eighteen rods of $1\frac{1}{4}$ inches in diameter: these rods pass through the flat ends, to which they are secured by collars on the inside and nuts on the outside. The rods average $8\frac{1}{4}$ inches from centre to centre.

The uptake is a separate construction of sheet iron placed against the front end of the boiler, which is nearly covered by it, with the exception of the front of the furnace and ashpit. It has the usual doors, hinged at top and giving access to the tubes for sweeping, etc. The chimney rises from the top of the uptake.

During the experiments, the boiler had no covering of any kind.

The following are the principal dimensions and proportions of the boiler:

Diameter of the shell,	8 ft.
Extreme length of the shell,	8 ft. 1 in.
Number of furnaces,	1.
Width of the grate,	4 ft. 6 in.
Length of the grate,	5 ft. 4 in.
Grate surface,	24 sq. ft.
Number of tubes,	119.
Outside diameter of tubes,	2·5 in.
Inside diameter of tubes,	2·3 in.

Inside diameter of ferrules for tubes,	2·0 in.
Length of tubes in the clear between the tube plates,	6 ft. 2¾ in.
Height of the chimney above the grate surface,	59 ft. 6 in.
Diameter of the chimney connection,	2 ft. 1½ in.
Cross area above the bridge-wall for draught,	6·0945 sq. ft.
Cross area through the tubes for draught,	3·4334 sq. ft.
Cross area through the ferrules of the tubes for draught,	2·5962 sq. ft.
Cross area of the chimney connection,	3·5465 sq. ft.
Heating surface in the furnace,	48·6 sq. ft.
Heating surface in the back smoke connection,	64·0 sq. ft.
Heating surface in the tubes, calculated for their inner circumference,	446·4 sq. ft.
Heating surface in the uptake,	14·0 sq. ft.
Total heating surface in the boiler,	573·0 sq. ft.
Square feet of heating surface per square foot of grate surface,	23·875
Square feet of grate surface per square foot of cross area above the bridge-wall,	3·938
Square feet of grate surface per square foot of cross area through the tubes,	6·990
Square feet of grate surface per square foot of cross area through the ferrules,	9·244
Square feet of grate surface per square foot of cross area of chimney connection,	6·767
Water room in boiler to 6 inches above top of tubes,	100 cub. ft.
Steam room in boiler above 6 inches above top of tubes,	75 cub. ft.
Weight of boiler, exclusive of grate-bars and chimney,	22100 pounds.
Weight of grate bars,	1210 pounds.
Weight of water in boiler,	6233 pounds.

Manner of Making the Experiments.

The experiments were made in the following manner:

A clean anthracite fire of 9 inches thickness having been brought to steady action, with the steam blowing freely from the boiler escape-pipe—the safety-valve having been previously removed from its seat—the water-level in the boiler was adjusted to 6 inches above the top

of the tubes, and the experiment held to commence. Each experiment continued exactly 12 hours, at which time the fire was thoroughly cleaned and made of the same thickness as at the commencement, with the water-level at the same mark.

During the continuance of each experiment, a tabular record or log was kept, in which was noted, at the end of each hour, the height of the barometer, the temperature of the air in the boiler-room, of the feed-water in the tank, and of the gases of combustion in the uptake, the latter being given by a metallic pyrometer. All the anthracite thrown into the furnace was carefully weighed, and all the refuse of ash, clinker and soot was likewise weighed on the same scales. After the completion of an experiment, the tubes were swept together with the other fire surfaces, so that each experiment was begun with a clean boiler. The boiler being entirely new, its water surfaces were quite clean. The water fed into the boiler was first accurately measured in tank. The steam pressure in the boiler was found to be slightly in excess of the atmospheric pressure. All the experiments were made by the same personnel and in the same manner; the anthracite being burned at the maximum rate of combustion which could be obtained without forcing the fire.

The boiler was without any non-heat-conducting covering whatever, and was situated in the still air of the boiler-house of the Steam Engineering department of the Washington Navy Yard. Every precaution was taken to insure accuracy in the results, and, also, that those from the different experiments might be fairly comparable. These results, and the data from which they were calculated, will be found in the following table.

The experiments were three in number. During the first, made on the 24th of May, 1873, all the tubes were in use. During the second, made on the 21st of May, 1873, the lower twenty-one tubes—ten on one side of the furnace and eleven on the other—were tightly plugged at both ends, so as to prevent the passage through them of any of the hot gases of combustion, thereby reducing the heating surface 13·75 per centum, or from a proportion of 23·8750 square feet to 1·0000 of grate surface, to the proportion of 20·5926 to 1·0000; the calorimeter through the tubes being thereby reduced 17·65 per centum, or from a proportion of 1·0000 square foot to every 9·2443 square feet of grate surface, to the proportion of 1·0000 to 11·2255. During the third experiment, made on the 23d of May, 1873, exactly the same reduc-

tions of heating surface and of calorimeter were made as in the second experiment, but, in this case, they were effected by plugging tightly at both ends the twenty-one tubes composing the upper row—the plugs used in the second experiment having, of course, been removed from the twenty-one lower tubes. The absolute areas and proportions of the grate surface, heating surface, and calorimeter through the tubes, in both the second and third experiments, were precisely the same, the only difference being that the reductions in these particulars from the quantities in the first experiment, were made in the second experiment in tubes *lying below the top of the bridge-wall*, and in the third experiment in tubes *lying above the top of the bridge-wall.*

The first and second experiments, therefore, permit the determination of the effect produced on the absolute and economic vaporizations of the boiler, by the simultaneous reduction of its heating surface and of its calorimeter through the tubes, its grate surface remaining constant, and all its heating surface lying above the top of its bridge-wall.

In the third experiment, 15·94 per centum of the heating surface, and 21·43 per centum of the calorimeter through the tubes, lay *below* the top of the bridge-wall, therefore, experiments second and third permit the determination of the effect produced on the absolute and economic vaporizations of the boiler by this distribution; the grate surface, heating surface, and calorimeters through the tubes being exactly the same in both experiments, the only difference being in the arrangement of the heating surface and calorimeter through the tubes relatively to the top of the bridge-wall. In the second experiment, all the calorimeter through the tubes was above that top; while, in the third experiment, only 78·57 per centum of the calorimeter was above that top. The grate surface and the calorimeter above the bridge-wall remained constant throughout, and the latter was so much larger than the calorimeter through the tubes that it exercised no influence on the results.

As the boiler, during all the experiments, had no covering to diminish the loss of heat by radiation from the external surfaces; and as boilers on which experiments are made, almost always have very efficient coverings for that purpose; it became necessary, in order that the results from this boiler may be comparable with those from other boilers, to ascertain the vaporizative value of the difference of the heat radiated in still air from the naked boiler and from the same boiler

under the same conditions when covered with the usual protector of hair felt 1½ inches thick. This has been effected by means of the constants in a table constructed from experiments made for this object by the writer, and published on page 161 of the March number of the JOURNAL for 1878. In that table, the number of Fahrenheit units of heat lost per hour per square foot of boiler plate per degree Fahrenheit difference of temperature between that of the steam upon one side of the metal, and that of the still air upon the opposite side, is 2·9330672 when the metal is naked, and 0·2507097 when the metal is covered with 1½ inches thickness of hair felt. The difference, 2·6823575 Fahrenheit units of heat, has been assumed, in the case of this boiler, to have been lost per hour per square foot of the 204 square feet of its exposed external surface, per degree Fahrenheit of difference of temperature between the temperature of the steam inside and that of the still air in the fire-room outside of the boiler. From these data and the latent heat of the steam, the vaporizations in the table due to the loss of heat by external radiation, have been calculated; and these vaporizations have been added to those given by the direct tank measurement, in order to obtain the normal vaporizations. As the experimental boiler was in the same room with other and much larger boilers in use, the temperature of the air in that room has been taken as the proper temperature for the calculation, instead of the temperature of the external air.

RESULTS.

If the atmospheric conditions governing the force of the draught, could be considered constant during the experiments, then the rate of combustion of the gasifiable portion of the anthracite was reduced, comparing experiments first and second $\left(\frac{4148-3625\times100}{4148}=\right)$ 12·61 per centum for a reduction of 21·43 per centum in the calorimeter through the tubes; that is to say, for a reduction from the proportion of 1·0000 square foot of calorimeter to 9·2443 square feet of grate, to the proportion of 1·0000 to 11·2255: all of the calorimeter in both cases being above the top of the bridge wall. Under these circumstances, the absolute vaporization was reduced

$$\left(\frac{36744\cdot067-31919\cdot145\times100}{36744\cdot067}=\right)\ 13\cdot13 \text{ per centum,}$$

the economic vaporization remaining sensibly unaffected notwithstand-

ing the reduction of 13·75 per centum in the heating surface. But had the absolute vaporizations been made the same in both experiments, by a proper reduction in the rate of combustion during the first experiment, the economic vaporization would certainly have been at least 6 or 7 per centum better in that experiment with all the tubes in use, than in the second experiment with a considerable portion of them plugged.

In the third experiment, the rate of combustion was sensibly the same as in the second experiment, but the absolute and the economic vaporizations were less. The first fell off

$$\left(\frac{31919{\cdot}145 - 30103{\cdot}678 \times 100}{31919.145} =\right) \text{ 5·69 per centum,}$$

and the last, correspondingly,

$$\left(\frac{10{\cdot}202 - 9{\cdot}680 \times 100}{10{\cdot}202} =\right) \text{ 5·12 per centum.}$$

If the absolute vaporization in the third experiment had, by means of a higher rate of combustion, been made equal to the absolute vaporization in the second experiment, then this difference of 5·12 per centum in the economic vaporization would have been considerably increased.

With regard to the temperature of the gases of combustion in the uptake during the different experiments, and comparing the first and second experiments, there is a difference of (867·5—814·2=) 53·3 degrees Fahrenheit in that temperature. The rate of combustion in the second experiment was 12·61 per centum less than in the first, but the heating surface was 13·75 per centum less also. Comparing, now, that temperature in the second and third experiments, in which the heating surface and the calorimeter were exactly the same, and the rate of combustion almost exactly the same, the temperature of the gases of combustion in the uptake was (814·2—785·0 =) 29·2 degrees Fahrenheit less in the third than in the second experiment, although 15·94 per centum of the heating surface in the former was less efficient than in the latter, owing to its position below the top of the grate bars. The effect of lessening the calorimeter is to lessen the air supply proportionally to weight of coal consumed, and it may easily be lessened to an extent that will materially affect the completeness of the combustion. Now, as the quantity of heat from a given weight of coal and, consequently, the temperature of the gases of combustion produced, are are lessened in proportion to the incompleteness of the combustion, too

By Chief Engineer ISHERWOOD, U. S. Navy.

E CONTAINING THE DATA AND RESULTS OF THREE EXPERIMENTS MADE ON A SINGLE FURNACE CYLINDRICAL MARINE BOILER AT THE WASHINGTON AVY-YARD, BY CHIEF ENGINEERS LORING AND BAKER, U. S. NAVY, WITH ANTHRACITE CONSUMED AT THE MAXIMUM RATE OF COMBUSTION, TO ASCERTAIN THE EFFECT PRODUCED ON THE ECONOMICAL AND POTENTIAL VAPORIZATION BY PLUGGING AT BOTH ENDS, FIRST, THE UPPER ROW OF TUBES (21 TUBES), LEAVING ALL THE OTHER TUBES IN USE; AND THEN PLUGGING AT BOTH ENDS THE LOWER 21 TUBES, LEAVING ALL THE OTHER TUBES IN USE, THE UPPER ROW HAVING BEEN UNPLUGGED. GRATE SURFACE, 24 SQUARE FEET. HEIGHT OF CHIMNEY ABOVE GRATE SURFACE, 59½ FEET.

		All the tubes in use.	*The lower 21 tubes plugged at both ends; all the other tubes in use.*	*The upper row of tubes (21 in number) plugged at both ends; all the other tubes in use.*
	Date of Experiment,	24TH MAY, 1873.	21ST MAY, 1873.	23D MAY, 1873.
OILER.	Number of square feet of heating surface in use,	573·0000	494·2228	494·2228
	Number of square feet of heating surface in use, per square foot of grate surface,	23·8750	20·5926	20·5926
	Number of square feet of cross area for draught above the bridge-wall,	6·0945	6·0945	6·0945
	Number of square feet of grate surface per square foot of cross area above the bridge-wall,	3·9380	3·9380	3·9380
	Number of square feet of cross area for draught through the ferrules of the tubes,	2·5962	2·1380	2·1380
	Number of square feet of grate surface per square foot of cross area through the ferrules,	9·2443	11·2255	11·2255
TOTAL NTITIES.	Duration of experiment, in consecutive hours,	12·	12·	12.
	Number of cubic feet of water vaporized according to tank measurement,	575·247	495·060	468·191
	Number of pounds of water vaporized according to tank measurement,	35862·000	30858·000	29190·000
	Number of pounds of water that would have been vaporized had the difference between the quantities of heat radiated from the boiler when naked and when clad with 1½ inches thick felt been so utilized,	882·067	1061·145	913·678
	Total number of cubic feet of water vaporized in the felt-clad boiler,	589·396	512·084	482·846
	Total number of pounds of water vaporized in the felt-clad boiler,	36744·067	31919·145	30103·678
	Total number of pounds of anthracite consumed,	4568·	4050·	4098·
	Total number of pounds of refuse from the anthracite in ash, clinker and soot,	420·	425·	486·
	Total number of pounds of combustible or gasifiable portion of the anthracite consumed,	4148·	3625·	3612·
	Per centum of the anthracite in refuse of ash, clinker and soot,	9·194	10·494	11·859
ATE OF BUSTION.	Pounds of anthracite consumed per hour,	380·667	337·500	341·500
	Pounds of combustible consumed per hour,	345·667	302·083	301·000
	Pounds of anthracite consumed per hour per square foot of grate surface,	15·861	14·062	14·229
	Pounds of combustible consumed per hour per square foot of grate surface,	14·402	12·587	12·542
	Pounds of anthracite consumed per hour per square foot of heating surface,	0·664	0·683	0·691
	Pounds of combustible consumed per hour per square foot of heating surface,	0·605	0·611	0·609
ESSURES.	Height of the barometer in inches of mercury, corrected for temperature,	29·40	30·04	29·48
	Steam pressure in boiler in pounds per square inch above zero,	14·60	15·00	14·73
EMPER- TURES.	Temperature in degrees Fahrenheit of the air in the boiler-room,	81·4	57·1	77·4
	Temperature in degrees Fahrenheit of the feed-water,	58·0	60·0	57·0
	Temperature in degrees Fahrenheit of the gases of combustion in the boiler-uptake,	867·5	814·2	785·0
POR- TION. *Economic. Absolute.*	Total number of pounds of water that would have been vaporized in the felted boiler had the temperature of the feed-water been 100 degrees Fahrenheit, and had it been vaporized under the standard pressure of 29·92 inches of mercury,	38173·352	33114·130	31306·454
	Total number of pounds of water that would have been vaporized in the felted boiler had the temperature of the feed-water been 212 degrees Fahrenheit, and had it been vaporized under the standard pressure of 29·92 inches of mercury.	42633·551	36983·206	34964·320
Economic.	Pounds of water vaporized from 100 degrees Fahrenheit by one pound of anthracite,	8·357	8·176	7·639
	Pounds of water vaporized from 100 degrees Fahrenheit by one pound of combustible,	9·203	9·135	8·667
	Pounds of water vaporized from 212 degrees Fahrenheit by one pound of anthracite,	9·333	9·132	8·532
	Pounds of water vaporized from 212 degrees Fahrenheit by one pound of combustible,	10·278	10·202	9·680

small a calorimeter may simultaneously cause both a lessened economic vaporization and a lower temperature of the gases of combustion in the uptake, although, generally, the latter would indicate a greater economic vaporization. The calorimeter through the tubes, which was small in the first experiment, being only the $\frac{1}{9.2443}$ of the grate, was reduced in the second experiment to the $\frac{1}{11.2255}$ of the grate, and, if only that portion of the calorimeter which is above the top of the bridge wall is effective, it was still further reduced in the third experiment to the $\frac{1}{14.2857}$ of the grate. Each of these reductions was probably attended by a more and more incomplete oxidation of the constituents of the coal, owing to a more and more insufficient air supply relatively to the weight of coal consumed. Thus the less and less temperatures of the gases of combustion in the second and third experiments may have have been due solely to their very small calorimeters.

These results show that, with a boiler of this type and of the proportions in the first experiment, both the absolute and economic vaporizations are injuriously affected to a marked degree by a reduction in the heating surface of 13·75 per centum, accompanied by a reduction of 21·43 per centum in the calorimeter through the tubes, the proportion of the original heating surface to the grate surface (23·8750 to 1·0000), and of the original calorimeter through the tubes to the grate surface (1·0000 to 9·2443), being so small that further reductions in either are attended by lessened results. Also, that, other things being equal, both the absolute and economic vaporizations are injuriously affected, and to a marked degree, by placing any considerable portion of the heating surface, and of the calorimeter through the tubes, below the level of the top of the bridge-wall.

Snow Illumination.—During a recent snow-storm, in the early afternoon, an interesting experiment was tried in Paris. At the moment when the sky was darkened by snow, the electric lamps were lighted in the square of the Théatre Francais. The reflection of the light from the snow-flakes immediately dispelled the darkness and produced a very pleasing effect. It is proposed to try a similar experiment in misty weather, and if the light can penetrate even to the distance of 20 metres (65·6 ft.), Jablochkoff lamps will be established at points where the passing is most frequent.—*Les Mondes.* C.

GAUGING AND MEASURING IMPLEMENTS.*

By J. Richards.

It is proposed in the following paper to offer some remarks on gauging or sizing implements such as are employed in machine fitting, and in explanation of some of the tools and processes required in securing precision in such implements.

It will be proper to explain at the beginning that nearly all my remarks, outside of some historical facts, must relate to experiments and results obtained in Philadelphia.

It is, however, thought that in dealing with this difficult branch of manufacture, no harm can arise from some notice of the progress made, especially as the firm of Messrs. Richards, Hand & Taylor, who have furnished the present drawings and examples, do not propose to deal so much with the element of mystery as has been done in some other cases.

For some reasons it would have been preferable to postpone any public notice of this manufacture until a later time, not in respect to implements or machines so much as the qualities of different kinds of material and some of the processes of manufacture, which are not sufficiently determined to be presented in a public essay. At some some future time the subject of material and processes may be brought before the Institute, if thought of sufficient interest.

It is well known to every one connected with engineering manufactures, that the maintenance of uniform or standard dimensions in machine fitting, is fast becoming a rule and almost a necessity, enhancing the value of what is made, and at the same time cheapening the cost of production by permitting a more extended division of labor.

The division of labor in machine fitting, as in nearly all branches of industry, depends on what may be called duplication, that is, producing one thing like another, so that different workmen may, independent of each other, prepare parts or pieces which can be assembled and put together without trying and hand fitting.

It will not be necessary to follow this principle into practical detail until the machines and implements are explained; the matter is alluded

*Paper read before the meeting of the Franklin Institute, February 19th, 1879.

to here merely to call attention, at the beginning, to the importance and possible extent of the duplicating system in machine fitting.

The export of American-made machines to Europe, commenced, we may claim, because of an early and successful application of the gauging system. One of the first and most important orders received from Europe for machinery, was for a nearly complete equipment of implements for the Enfield small-arms factory, in England; machines and tools the main object of which was a duplication of their product. Watches, clocks, sewing machines, small arms, with many other articles of a similar kind, are now made in this country and sold in Europe because the system of gauging and duplicating, offers an advantage overbalancing cheaper labor, cheaper material and more than 3,000 miles of ocean carriage.

Referring now to machine shop gauges, it is well known that most of our larger establishments have been supplied with standard gauges imported from England, usually a set of pins and collars such as are shown in Fig. 1, and corresponding to what is called the Whitworth standard. Most of these gauges are made in the works of the Whitworth company at Manchester, who by long experience and their reputation for good work, have controlled this manufacture. Of late years, however, some fine examples have been made in this country, but at prices much greater than are demanded for English gauges.

Fig. 1.

Pins and collars—or cylindrical gauges as they are generally called—were, so far as we have any record, first made by the celebrated John G. Bodmer, of Manchester, a Swiss engineer who may be regarded as the compeer of Sir Joseph Whitworth in machine tool improvement. For thirty years or more these pins and collars have been made with great exactness, the fitting surfaces highly polished and in every respect a marvel of exactness and uniformity.

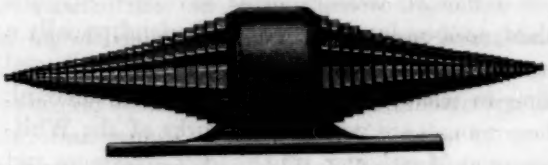
Before entering upon a description of the tools made and machines employed in the American Standard Gauge and Tool Works in Philadelphia, some history of the origin of the scheme will not be out of place.

In 1860 the writer, while engaged as a manager in the Ohio Tool Company Works, at Columbus, Ohio, feeling the want of some means of maintaining sizes and not having sufficient use for such implements to justify the purchase of a set of pins and collars, conceived the idea of introducing some cheaper system, by which fixed calipers with some

simple means to keep them in adjustment, would take the place of pins and collars.

The matter was followed up and calipers of several kinds were made, also a corrective gauge not differing much from the one shown in Fig. 2. In 1867 patents were procured for an improved method of making fixed calipers from steel plates, also for the corrective cone gauge or the standard before mentioned, but circumstances at the time prevented the manufacture of such implements and nothing was done until 1869, when the writer came to Philadelphia with a view of seeking some one to join him in the manufacture of gauging implements. Failing in this, he went to England, partly upon other business, but mainly to gain some information in respect to the manufacture and use of gauges in that country.

Fig. 2.



Investigations there, so far as possible at the time, led to the opinion that a considerable amount of capital would be required, especially in providing machinery for making calipers, and the business was abandoned again until 1872 when, in one of the front offices of the Franklin Institute building, drawings and specifications were prepared for nine special machines to be employed in gauge making. Among these machines were most of those now in use at the works, Twenty-second and Wood Sts., in this city.

A year later, the other front office on the north side, formerly occupied by Mr. Geyelin, was rented for the gauge business, Professor Morton, then Secretary of the Franklin Institute, proposing, if practicable, to fit up a portion of the basement of the building as a workshop.

In 1873, just at the beginning of trade depression, a contract was made with Mr. B. D. Whitney, of Winchendon, Massachusetts, to construct the gauge machines, and they were completed in nine months time, but the state of business was then such that the machinery was packed away as soon as completed and was never set up until August, 1877, when practical operations were for the first time com-

menced. This was seventeen years from the time the scheme began, but it had been followed in one way or another continually during that time.

It was thought that in a month or so, calipers and corrective gauges would be ready for sale, but these expectations were foiled by several circumstances, principal among which, was the failure of the measuring machine fitted with graduating screws made at the Whitworth Co.'s works in Manchester and guaranteed as to accuracy.

This matter had before been thought of, but there was scarcely a doubt that the pitch of the screws was correct. Subsequent experiments, however, proved that not only the aggregate pitch was wrong and the screws not parallel, but the relative pitch in so short a length as seven inches would not do to depend upon. These screws were, no doubt, as their appearance indicated and as the Whitworth Co. afterwards maintained, carefully made, but the delicacy of measuring tests demands more accuracy than can be attained by relying upon the pitch or movement of screws.

The first experiment in measuring was made by preparing six rods of Stubb's wire, the points nicely finished by stoning and the central part covered with several layers of thick, soft paper to prevent induction. These rods were carefully fitted into the machine when set at six inches, temperature and other conditions being carefully observed. The rods were then uncovered and fitted into a groove cut on the side of a bar of pine wood and taken to Messrs. W. B. Bement & Sons' works, where a Whitworth master screw, with the necessary conveniences for testing the rods, was supplied and even the experiments conducted by the firm, who were kind enough to take a great interest in the matter. By careful comparison it was found that the measuring machine in comparison with the screw recorded about one in ten thousand short. This, of course stopped gauge making for the time. The test rods were then taken to London and in three separate experiments on different standards, two made by myself and one by Gen. B. F. Tilghman, a member of the Institute, it was found that the rods were short, the variation being but little in the three cases and corresponding very nearly with the less perfect experiment at Philadelphia.

The next operation was to procure four standard test rods, adjusted to the Imperial yard of Great Britain and its divisions, by which the measuring machine in Philadelphia could be adjusted. Such rods were prepared in London, with great care, by those having access to

the imperial standard, and Mr. George Richards, then in England, brought them out to Philadelphia and began the correction of the measuring machine, proving by combinations of the rods, comparing with Whitworth gauges, and so on. In the mean time, another set of test rods were preparing in Manchester, England, and were forwarded to Philadelphia to prove the first set and also the machine which had then been tolerably well adjusted.

Rods were next adjusted by the Whitworth company at Manchester, and the Standards Department at Washington was visited; in short, all was done that could be done to fix a standard for measurement, and it is now thought that the machine is as nearly accurate as one can be made.

This will be a proper place to explain that the object in seeking for standards in Great Britain was to match what is called the Whitworth scale now in use in our workshops. Many people suppose the Whitworth standard to be an arbitrary and independent one; in fact, this idea is promulgated by the company, because if inquiry is made at the works whether their standard is the same as the Imperial one, the answer will be (or was in one case), "they did not know, they had their own standard." Imagine Sir Joseph Whitworth & Co. preparing gauging implements which did not correspond to the standard of the realm!

A prevalent opinion exists that the British and American standards for lineal measure are not the same. This idea, I have been informed by Mr. John W. Nystrom, came from publications of the Smithsonian Institution,* but a moment's reflection must show how improbable it is that there is any difference in the lineal measures used. The British standard is an arbitrary one, fixed after several years of labor on the part of a learned commission and at considerable expense. The pendulum test, which was the only natural one by which experiments were made, was abandoned after thousands of readings showed its inconstancy. The French metre of the forty-millionth part of the earth's meridian, as well as all other natural standards, were abandoned for the same reason, and the wisdom of this course has been proved by the French government since adopting an arbitrary standard the same as the English had done.

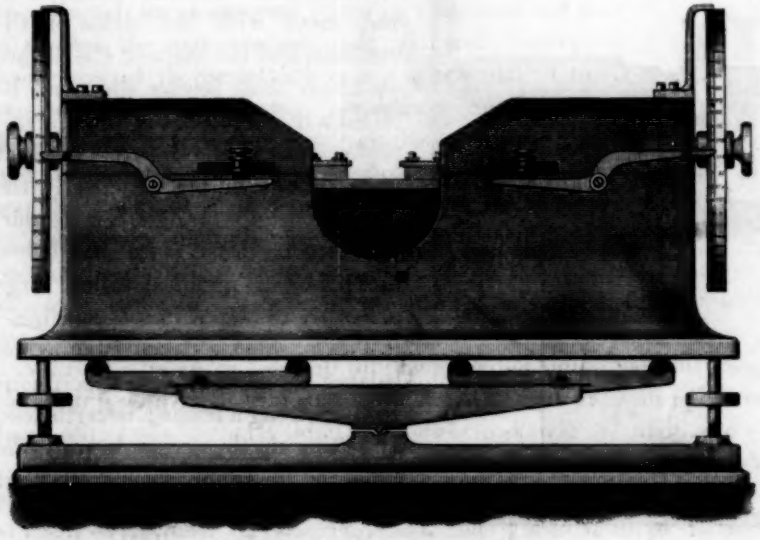
In this country, while there has been more spent in preparing comparative standards than by any other government in the world, there has been no search, so far as I know, after natural or other standards. The equipment of implements of transmission and for

* See "Smithsonian Miscellaneous Collection," vol. i, p. 112 D.

measuring, exceeds that of which any other country can boast, but the principal wisdom shown in the matter, has been in avoiding the useless expense of fixing an independent standard which might be anything.

By comparison, under similar conditions, a metal test rod adjusted at Washington and a similar one adjusted at London would show a difference due to ten degrees of temperature, and this is, no doubt, the only difference. It is enough to know that gauges made to a carefully adjusted standard here will match and interchange with those made in England.

Fig. 3.



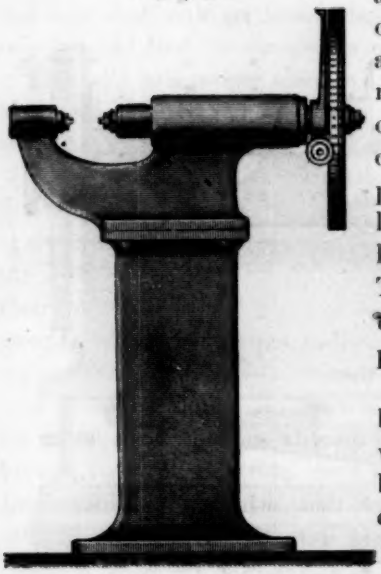
Proceeding, now, to notice more particularly the measuring machine shown in side elevation at Fig. 3: It consists of a strong frame, on the top of which are two traversing slides very carefully fitted and moved by screws. The contact points seen at the centre are of hardened steel made parallel by careful fitting. The index wheels at each end are to count the revolutions of the screws or divisions of the same. One of the screws has a pitch of eight threads to an inch for the ordinary divisions marked on rules and scales, and the other screw is ten per inch for decimal divisions.

In measuring, the points are brought together in easy contact to form a base or starting point and then expanded by turning one or the other of the wheels, or both, counting the revolutions or parts of revolutions to

determine the distance between the points or the size of what is to be measured. On one side the number of divisions is 1000, hence with a screw of ten threads to an inch, each division on the wheel equals $\frac{1}{10000}$ of an inch at the points.

The movable indices on the front of the machine are to correct the imperfections of the screws on a principle which, so far as is known, was invented by Professor John E. Sweet, of Cornell University.

Fig. 4.



The two set screws seen in front and resting against the upper surface of the index bars are attached to and move with the slides of the machine, and the shape of the surface on which these screws slide may be called a diagram of the screw's imperfections. In the drawing, straight lines are shown, but practically the lines are neither straight nor regular. The wooden throat piece seen below the points is removed when large pieces are to be put in the machine.

The machine is shown mounted on balance bars, which seem superfluous with so strong a frame; nevertheless, by setting up the screws beneath the ends of the frame, a very apparent change in the readingswill be seen.

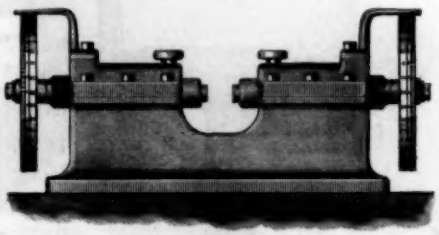
Fig. 4 is what is called a calipering machine, used for transmitting sizes, but not for measuring beyond a degree of accuracy which the pitch of a carefully made screw may give. Such machines are employed in making gauges, reamers, drills, mandrils, taps and so on.

Being inflexible, or nearly so, the accuracy is greater than in using common calipers, but the main difference and that which gives most value to such machines is that they indicate as the size is approached and also variations above or below standard size by $\frac{1}{10000}$ of an inch.

A workman using such a machine has no dread of spoiling his work. He can make a loose fit, a shrinking fit, or a forced fit, as may be required. The value of such a machine in a fitting shop was never conjectured until one was made and put into use at the gauge works.

At first it was intended for use only in grinding mandrils or gauges, but soon became an implement of general use. A workman would finish a piece of turned wook to $\frac{5}{1000}$ or $\frac{10}{1000}$ of an inch in diameter without losing any time. Seeing the value of such a machine, especially for the tool rooms of large machine shops, and also requiring more of them in the gauge works, a smaller and cheaper machine, measuring to 4 in., was prepared. This machine as shown in Fig. 5, is arranged with divisions at one end for the $\frac{1}{5000}$ of an inch and at the other end for $\frac{1}{3200}$ of an inch.

Fig. 5.



The same machine can be adjusted for measuring, if desired, the index points being shaped to correct irregularities of the screws. This is done by experiments and comparison with the standard machine, Fig. 3.

The makers incline to the opinion that machines of this kind will come into general use and are experimenting on various modifications to perfect and cheapen them.

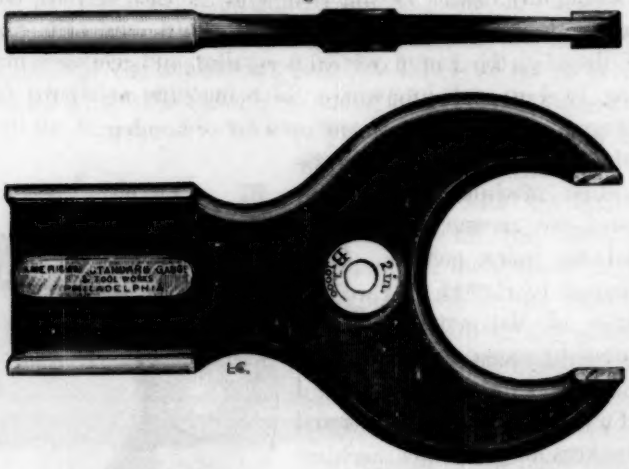
With this much in respect to the machines employed in gauge-making, it will be next in place to describe some of the implements produced.

It was noticed in various shops that, whether provided with cylindrical gauges or not, fixed calipers were the implements in use, in other words, were the working tools, and it was resolved to make these a base, as it were, for gauging, reversing the old system, which would procure the most expensive gauges for reference, and then go downward to calipers and other tools; nevertheless a set of calipers with some means to keep them in adjustment forms a tolerably complete equipment to maintain sizes in a machine shop. There are, in such a case, but few, if any, tools not in practical use, while the original cost is only a fourth to a third as much as under the old system.

After various experiments with moulded steel, it was found to be suitable for calipers. When prepared for the purpose, it would harden the same as cast steel and, when carefully treated, was free from inherent strains. Several different forms were tried, the result being finally to adopt the one shown in Fig. 6.

To keep these calipers in adjustment there are furnished what are called corrective gauges, shown in a cheap form in Fig. 2, and in the

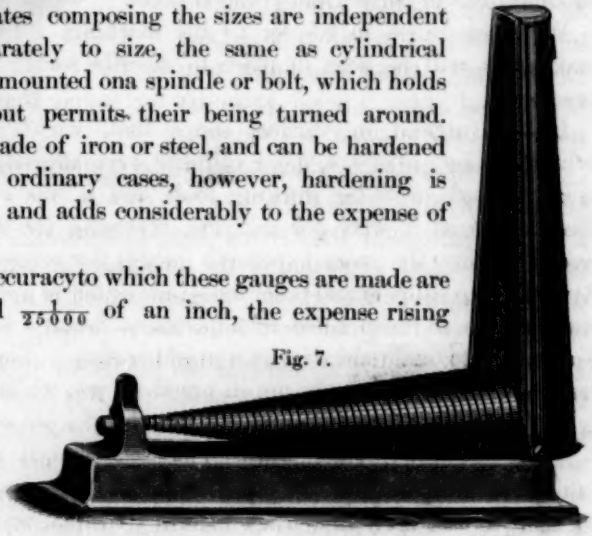
Fig. 6.



usual form in Fig. 7. These gauges are like what are called step gauges in appearance, but are made on a wholly different plan. The discs or plates composing the sizes are independent and ground separately to size, the same as cylindrical gauges; they are mounted ona spindle or bolt, which holds them together, but permits their being turned around. These discs are made of iron or steel, and can be hardened if required; for ordinary cases, however, hardening is of noimportance, and adds considerably to the expense of preparing them.

The limits of accuracyto which these gauges are made are $\frac{1}{5000}$, $\frac{1}{10000}$ and $\frac{1}{25000}$ of an inch, the expense rising with the degree of accuracy, but not in the same proportion.

Fig. 7.



The sizes are usually from $\frac{1}{4}$ to $2\frac{1}{2}$ inches by sixteenths, and from $2\frac{1}{2}$ to 4 inches by eighths of an inch, making 49 sizes, which can be mounted in an iron case, as shown, and be

kept in the hands of a manager or foreman, who can at pleasure inspect and test the calipers in use.

If any wear or derangement exists, a caliper can be corrected by a careful blow on the outer or inner edge, as the case may be, requiring but a moment's time, and but little skill after a few experiments.

Fig. 8 shows a kind of fixed calipers, made of steel or white iron; the latter is recommended for rough use, being extremely hard throughout, and not liable to derangement by wear or accident.

Fig. 8.

Pins and collars, which seem to be the most expensive and difficult kind of gauges to make, are by no means so if, as before mentioned, time is not taken into account. The pins are first made and the collars lapped out to fit; but by this remark it must not be inferred that the pins are ground to size by common emery wheels and in an ordinary grinding machine. Speaking for ordinary practice, this is not the case, because neither the nature of grinding wheels or the movements for traversing, have been found perfect enough to finish pins to size, and there is good authority for saying that none have been finished in this manner in England.

The fixed calipers, which seem to be the most simple to make, are nevertheless the most difficult, and require more implements and processes than anything else. They are more subject to change from temperature, and a portion of the grinding for adjustment has to be done on the faces of wheels, an operation which is in all cases extremely difficult, even if accurate results are not required.

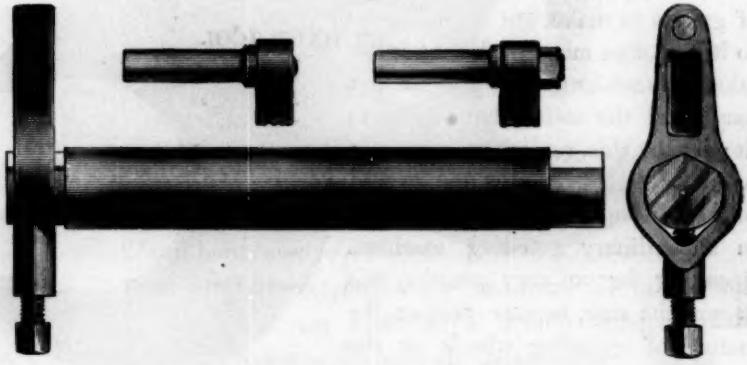
The great variation of temperature between winter and summer is a considerable difficulty in gauge-making in this country.

The lower temperature of winter can of course be controlled by artificial warming, but the heat of summer is not so easily provided against; so that in assuming a scale of temperature, 70° has been adopted at the Standards Department in Washington, and the measuring machine, Fig. 3, has been adjusted at that temperature. In England

62° is the common standard, while in Northern Europe a lower scale is common.

The maintenance of standard sizes in a machine shop involves a good many things beside gauges, but fortunately nothing which should not be provided at any rate. Turning mandrels, for example, must be kept up to correspond. In former times turning mandrels were made of iron, consisting generally of scrap pieces of various lengths, and were usually turned off to fit each time they were used, and on the

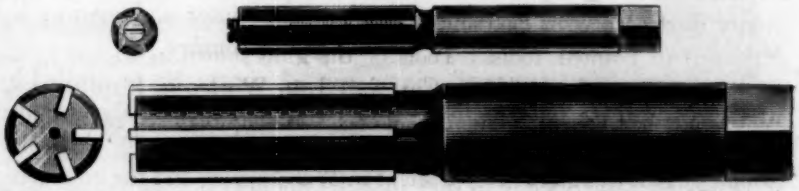
Fig. 9.



whole constituted what might be called a nuisance in a machine shop. Now it is evident that if holes are bored to uniform size, one mandrel of each size will do in a tolerably large shop, and if that mandrel is made of steel, hardened and ground to size, the expense of "maintaining it," as we may say, is reduced to a minimum.

The engraving, Fig. 9, shows a very good form for mandrels and drivers also. The ends are shaped with two polygonal sides, which fit into a corresponding seat in the driver, as seen in the end view.

Fig. 10.



The driving studs, as shown on the smaller ones, are separate, and can be removed if not required.

Fig. 10 shows reamers for machine fitting, which can be expanded as they wear away. The smaller one is drilled out centrally, and then mortised between the blades, so that a conical plug forced in by the screw at the end expands the centre of the reamer. The larger one is a blade reamer of the usual type, and needs no explanation.

Fig. 11.

RIGHT HAND TOOL.

Among the tools made at the gauge works in Philadelphia, but in no way connected with gauging, are tool stocks with separate or detachable points, held by screw-keys in a very secure manner. A great many modifications of such tools have been tried in this country and also in Europe, but none except the present form seem to have met the expectations of their inventors.

Fig. 12.

LEFT HAND TOOL.

In Figs. 11, 12, 13 and 14 are shown side views of such tools, those for flat cutting having cylindrical cutters or points, a form not so commonly used here as in England, but having more endurance for heavy cutting than pointed tools. Tools of the kind shown in Figs. 11 and 12 are in general use at the Cornwall Iron Works, in Birmingham, England, where the expense of cutting and shaping iron, in so far as the writer can judge, has been reduced to its lowest limits.

The purposes arrived at in such tools are not always apparent at a first examination, and may be briefly mentioned as follows: (1) The points, being only small pieces, can be made of finer steel than can be afforded for

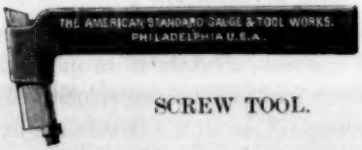
solid tools. (2) The points can be instantly removed or replaced without disturbing the tool stock. (3) The points being duplicates, no time need be lost in sharpening, a fresh point being inserted when necessary. (4) Tool dressing, an expensive and generally unsatisfactory branch, is dispensed with. (5) In grinding the tools a large number can be

Fig. 13.

SWIVEL TOOL.

treated at one time; and there being but one grinding angle and that a constant one, no skill is required in the operation. (6) The height of the point of the tool can be regulated at pleasure, thus avoiding what is called tool raising appliances on engine lathes.

Fig. 14.



SCREW TOOL.

The screw-cutting modification will be understood without further explanation, but it may be mentioned that in practice it has proved wholly successful.

The cylindrical point tools are a modification of quite an old invention, originating in Glasgow, and one of the examples shown is from England, where tools of this kind are gradually coming into use.

Mediterranean Tides.—M. Roudaire and Admiral Mouchez have observed tides of 2·5 metres (7·79 ft.) in the Gulf of Gabes. The Venetian tide of ·8 metre (2·6 ft.) is the highest previously observed in the Mediterranean.—*Comptes Rendus.* C.

ON D'AURIA'S ENGINE GOVERNOR.

By the Inventor, PROF. L. D'AURIA.

Whatever may be the scientific principle on which a steam engine governor is constructed, it is easily seen that when in operation all the forces acting on it can be reduced to two acting on its valve in a contrary direction to each other, one trying to shut the passage of the steam, the other to open it.

The first force is produced by the velocity which the engine communicates to the governor, and consequently is a function of the velocity of the engine; the second force is produced by a weight or by the elastic force of some spring.

Let P and Q be respectively those two forces, and W the velocity of the engine; will be

$$P = f(W);$$

and for the equilibrium of the valve, which is supposed to be balanced by the steam, that is, independent of the pressure of the steam, must be

$$Q = P = f(W) \qquad (1)$$

As the pressure of the steam in the boiler, as well as the load of the engine, are subjected to variations, the engine cannot be rigorously governed if the valve is not in equilibrium in all its positions between the limits of its stroke with a constant velocity W of the engine.

Therefore the equation (1) must not be affected by the changes of position of the governor in reference to itself, or it must be independent of the cöordinates of the system constituting said governor. And if the force P is a function of those cöordinates (as takes place in all the governors constructed on the principle of centrifugal force), then, also, the other force Q must be a function of the same cöordinates, but such that the equation (1) results independently of them.

Let, now, H be the friction of the governor, considered at the same point of application of the forces P, Q. The equation of equilibrium of the valve when it moves so as to shut the passage of the steam, will be

$$Q + H = f(W); \qquad (2)$$

and, when the contrary takes place, will be

$$Q - H = f(W) \qquad (3)$$

Subtracting the equation (3) from the other (2), will be

$$2H = f(W) - f(W) = o,$$

which is absurd unless H is equal to zero, or the value of W in the equation (2) is greater than that of W in the equation (3). But in this case, at every change of direction in the motion of the valve, a variation of speed takes place in the engine, more or less, according to the value of the friction H; therefore, to obtain a perfect governor it is not enough that the equation of its equilibrium is independent of the changes of position of said governor, it must be independent also of friction.

Having thus established the conditions to be satisfied in the construction of a perfect governor, my first step toward the solution of this important problem was the elimination of the friction of the valve-stem in its stuffing box, which I consider the most pernicious to the sensitiveness of a governor.

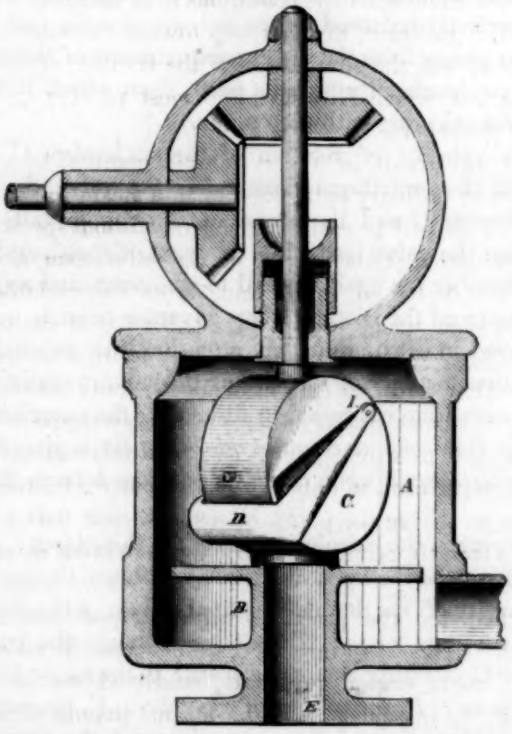
I obtained this result in a very simple manner, by enclosing the mechanism of an ordinary ball governor in a steam chamber in which it revolves. This will be easily understood without special illustration. With the elimination of the friction of the valve-stem, another serious inconvenience is destroyed, that arising from the variable pressure of steam on said stem, which prevents the balancing of the valve.

The use of heavy balls being unnecessary in this improved form, I immediately thought to reduce the mechanism to only one ball and its arm, the valve and its valve chamber; after which I saw the possibility of using the ball arm itself as valve, pivoted on a movable valve chamber, thus reducing the mechanism to only two pieces, and the friction to its minimum, that is, to that of the points of suspension at the ball arm transformed into a throttle valve, which friction is so small as to be neglected in calculations.

One method for the practical realization of my last improvement, which seems to me to exhibit the greatest degree of simplicity in steam engine governors, isfully shown in the annexed drawing (Fig. 1) in which A is the steam chamber having in the centre of its bottom a vertical and cylindrical tube B, open at both ends and prolonged partly inside and partly outside of said steam chamber. C is the movable valve chamber in the drawing, having the form of a short cylindric box or case. It fits the upper part of the tube B, and is fixed on a vertical shaft receiving motion from the engine in the manner shown in the drawing. When this shaft is in motion, it revolves the valve chamber C around its seat B, but without any friction. The ends of the cylindrical valve chamber

C are closed by two parallel walls disposed vertically. On each of them is cut an equal port, conveniently shaped and situated so as to be regulated simultaneously by the oscillating double-weighted valve *D*, composed of two equal slide valves, sector-shaped, rigidly held parallel to each other internally by a bridge *D*, of proper weight, and hung by centre pins on the parallel walls of the valve chamber, so as to oscillate freely on the outside of them in a vertical plane.

Fig. 1.



The stroke of the double-weighted valve *D* is limited to open and shut the ports of the valve chamber without any lost motion. The centre of gravity of the valve is situated below the horizontal plane, passing through the axis of suspension *I*, and the right line joining the mean point of this axis with the centre of gravity, is crossed by the axis of rotation of the valve chamber at an angle of about 45°, so that, when the governor is put in motion the effect of centrifugal force will

be to turn the double-weighted valve D on its axis of suspension I, and close the ports on either side of the valve chamber C.

The inside of the steam chamber is divided in two compartments by a disc or diaphragm attached to the shell of the tube B, leaving all around its periphery an annular passage for the steam to flow from the lower compartment to which it is first admitted to the upper one, in which runs the mechanism C, D.

The object of this is the uniform distribution of the steam around C, D without affecting the double-weighted valve D, which, in consequence, is perfectly balanced.

The steam passes from the upper compartments of the steam chamber into the valve chamber through its ports, from which it flows into the tube B, communicating with the engine.

When the velocity of rotation of the mechanism C, D exceeds a certain limit, the centrifugal force raises the valve, the ports of the valve chamber shut, and the speed of the engine falls for want of steam. Then the valve itself falls for want of speed, and the ports of the valve chamber are again opened to the steam, and so on.

Having reduced the friction of my governor to such a minimum as to be neglected in calculations, my attention was directed to find the most convenient manner of suspending the valve, to satisfy as closely as possible the condition expressed in discussing the equation (1), that is, the condition that *with a constant velocity of the engine, the valve must indifferently be in equilibrium in all its positions between the limits of its stroke.*

The following is the calculation made for this object:

Let xx (Fig 2) be the vertical axis of rotation of the governor; C the centre of gravity of the double-weighted valve; y the distance of this point from the axis xx; T T the tangent line to the curve described by the point C, touching this same point; θ, the angle formed by T T with the axis xx; P, the weight of the valve; F, its centrifugal force, and N the number of revolutions per minute of the governor.

The equation of equilibrium will be

$$F\sin\theta = P\cos\theta \qquad (4)$$

The value of F expressed in function of y and N is

$$F = \frac{P N^2 \pi^2 y}{900 \times g}$$

Substituting it in the equation (4), after reductions will be found

$$\frac{N^2\pi^2 y}{900\times g}tang\theta = 1 \qquad (5)$$

or

$$ytang\theta = \frac{900\times g}{N^2\pi^2} = Const := C$$

If the axis xx is considered as axis of abscissas of the curve described by the point C and y as an ordinate of the same, will be

$$tang\theta = \frac{dy}{dx}$$

Substituting this value in the last equation, will be

$$ydy = Cdx;$$

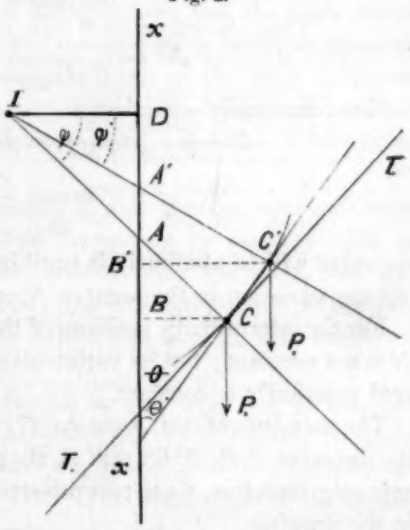
and

$$\int ydy = C\int dx;$$

or,

$$y^2 = 2Cx$$

Fig. 2.



This equation represents a parabola; therefore, to satisfy mathematically the above-mentioned condition, the point C must move on such curve.

I could obtain this effect practically by suspending the valve with a chain, which develops from a parabolic outline, it being known that the evolute of a parabola is another parabola. But, as the oscillation of the valve is short, the parabolic arc described by C can be considered approximately as an arc of circumference having for its centre the mean centre of curvature of said parabolic arc; and this centre be considered as point of suspension of the valve.

Now, as the co-ordinates of this point are

$$\text{Abscissa} = e + \frac{3y^2}{2e}; \qquad \text{Ordinate} = -\frac{y^3}{e};$$

it is evident why the axis of suspension I, I, of the valve, is situ-

ated, as shown in Fig. 1, in reference to the centre of gravity of said valve and the axis of rotation of the valve chamber.

But this disposition is not at all arbitrary, as it seems to be, because the axis of suspension I, in reference to its position and its distance from the centre of gravity C, can be determined by calculation so as to obtain the equilibrium of the valve in all its positions with the smallest variation of N; that is, with the smallest variation of speed in the engine.

In fact, let IC, IC^1 (Fig. 2) represent the extreme positions of the valve; φ and φ^1 their respective angles with the horizon; and let

$$ID = a; \quad IC = IC^1 = R;$$

$$\therefore \quad y = CB = R\cos\varphi - a$$

$$y = C^1B^1 = R\cos\varphi^1 - a.$$

Substituting successively those two values of y in the equation (5), observing that $\varphi = \theta$, $\varphi^1 = \theta^1$, will be found, after reductions,

$$\left.\begin{aligned} N^2 &= \frac{C}{R\sin\varphi - a\,\mathrm{tang}\varphi} \\ N^2 &= \frac{C}{R\sin\varphi^1 - a\,\mathrm{tang}\varphi^1} \end{aligned}\right\} \quad (6)$$

Now, it is easily seen, that if

$$R\sin\varphi - a\,\mathrm{tang}\varphi = R\sin\varphi^1 - a\,\mathrm{tang}\varphi^1; \quad (7)$$

or,

$$R = a\,\frac{\mathrm{tang}\varphi - \mathrm{tang}\varphi^1}{\sin\varphi - \sin\varphi^1}$$

the valve will be absolutely in equilibrium at its extreme positions without any variation in the number N, or of speed in the engine.

For the intermediary positions of the valve, theoretically, the number N is not constant; but its variations are so small that it can be considered practically as constant.

The members of the equation (7) represent, respectively, in Fig. 2, the distances $A\,B$, A^1B^1, that is, the projections of $A\,C$, A^1C^1 on the axis xx; therefore, those two projections must result equal to each other in the drawing.

Gallium Battery.—J. Reynauld has succeeded in making a battery of liquid and solid gallium by means of a metal solution of gallium sulphate. The liquid metal takes the place of zinc; the solid, of copper; the former being negative in relation to the latter.—*Fortschr. der Zeit.* C.

CONICAL ARCHES AT SOUTH ST. BRIDGE, PHILA., PA.

By D. McN. Stauffer, C. E.*

The Eastern approach to South St. Bridge in this city is made up in part of a somewhat peculiar piece of arch-masonry, and as it contains certain novel features, that might be applied with advantage at other points, we will attempt to briefly describe it.

The centre lines of South St. and the bridge proper intersect each other at an angle of 33° 25′ necessitating a curve in the approach from the East, and to conform in design with the "late lamented" Western approach, this curve was pierced by three arches.

The ordinary practice in arches on a curve is simply to widen the pier ends towards the outside of the circle, and leave the arches themselves "right arches." But it was thought here that the work could be much improved in appearance and a considerable saving in masonry and foundations attained, by leaving the piers of the same thickness throughout, and throwing the eccentricity into the arches, and to this end the following plan was determined upon, after due deliberation and numerous experimental plans.

The foundations of all the masonry in the Eastern approach were upon hard gravel—timber platforms supporting the masonry—but as this gravel stratum communicated directly with the river, and was from 12 ft. to 15 ft. below high tide; the foundations were expensive, and any reduction possible in their extent was an item well worthy of consideration.

The roadway of the approach was 55 ft. wide from out to out, and the centre line of the curved portion, which curve was entirely occupied by the three arches, was located with a radius of 169 ft. 6 in, with an included angle at centre of 33° 25′. The abutments of the arches were consequently upon the tangents to the curve.

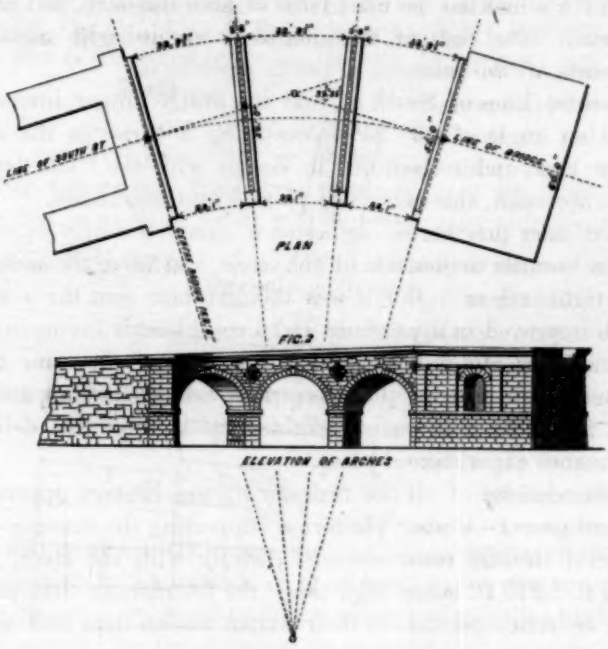
Each one of the two arch piers was 55 ft. long, 5 ft. 6 in. thick, throughout, and 12 ft. high from foundation to the springing line of the arch. The material used in these piers was Port Deposit granite, rock-face ashlar, cut in courses of from 17 in. to 27 in. rise, with "through headers" liberally distributed throughout the length of the

* A paper read before the Engineers' Club of Philadelphia.

pier. The Skewback and coping, forming one piece was of Maine granite, hammer-dressed, and nearly every other section extended across the pier, making a double skewback, the sections averaging 4 ft. in width.

The centre line of each pier was located on a radial line of the

Fig. 1.

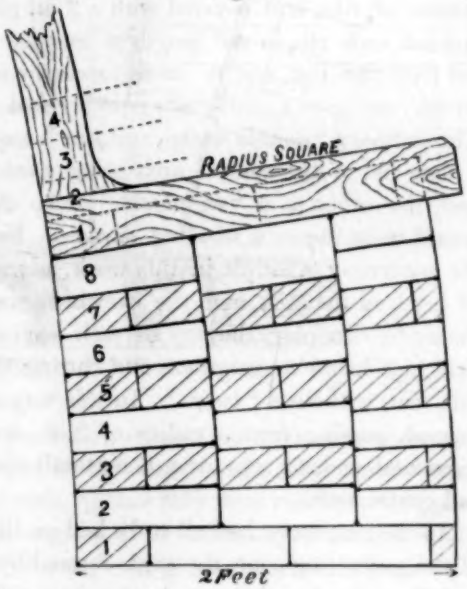


curve, the sides of the pier being parallel to this radius, and 2′, 9″ distant from it. The bounding radii of the curve fell in like manner 2′ 9″ inside the abutments, making the plan of the three arches equal, and in dimensions as follows: Each arch was 55 ft. long, the chord span at the inner end 22 ft. 1 in., and at the outer end 32′ 9⅜″. The

rise of the arch was 11 ft. ½ in. throughout, the springing line and crown of the arch being both horizontal.

This arch is really a portion of a cone, and may perhaps be better described as follows: The line of the *crown* of the arch would fall in the "slant height" of the cone, and the plane of the *springing line*, would be a plane parallel to the slant height, and cutting the axis of the cone at the point which represents the face of the smaller end of the arch, thus making the rise at that smaller end equal to one half its chord span. The ends of the arch were cut at right angles to the slant height of the cone, and would be theoretically ellipses, but in this case the angle made with the axis of the cone was so nearly 90° that they were treated as circular arches. The fact that the springing lines were actually the flatter portions of a parabola — instead of straight lines—was in like manner, and for a like reason, disregarded.

Fig. 2.



The smaller arch was regarded as a full centred arch of 22′ 1″ span and 11′ 0½″ rise, and the other as a "segmental" arch of 32′ 9⅜″ span, and 11′ 0½″ rise.

Maine granite was used for the ringstones and hard burned brick for the arch proper. The brick ring was 24 in. thick, and laid in cement mortar, formed of one portion Rosendale hydraulic cement and one part clean sharp river sand. The bond used in the brickwork can be better understood by an examination of the accompanying Fig. 2. The advantages of this bond were as follows: First and most important, by this arrangement, the thickening of the mortar joint as the extrados of the arch was approached was confined to the *length of one brick*, and this would be the case no matter how thick the ring,

2d. The arch was divided in its length into a series of true voussoirs, the bond repeating itself in each 8 courses. And 3d. The intrados of the arch was uniform in appearance, the bond being a "header and stretcher bond" everywhere; in case of any settlement and consequent cracking of the arch, bricks arranged as these were could not fall out of the arch as readily as in a bond formed of a *series* of headers and a *series* of stretchers alternating, a common form of arch masonry.

The arch centres were built of 8″ × 8″ white pine timber and 2 in. plank, bolted together with 1 in. bolts; they were spaced 5 ft. apart from centres of ribs, and covered with a 2 in. planed lagging. The chord span of each rib, in the length of any one arch, was of course different from the rest, and to insure accuracy in this point, each rib was struck out upon a platform separately and framed on this platform. The ordinary "double wedge and key" was used in striking them.

One end of the conical arch being treated as a "full centre" arch, and the other as a "segmental" arch, the skewback joining them would be in theory a winding surface. But as economy of cash was the governing principle in this work, advantage was taken of the use of brick in the arch, and the skewback was made to approximate to theory by dropping the top of each section, say every four feet, one half inch below its neighbor, and cutting the face of the skewback to suit, cut without a "twist." In this way a series of slight steps was formed, passing from a radius of 2 ft., and a sine of 10 in. at the segmental end, to zero or a horizontal plane, three feet back of the full centre arch.

As the ringstones had all to be laid on lines radiating from the apex of the generating cone, the angle formed by the *face* of each ringstone and the *intrados* of the arch was one uniformly but constantly varying from the key to the springing line. The keystone was the only one in which this angle was just 90°. In the segmental arch the angle *increased* from 90° at the crown to 95° 20′ at the spring, and at the full centre end the angle *decreased* from 90° at the crown to 84° 40′ at the springing line. Each ringstone taken in the direction of its length was wedge-shaped, with its face wider or narrower than its back as it was located in the segmental or full center end of the arch.

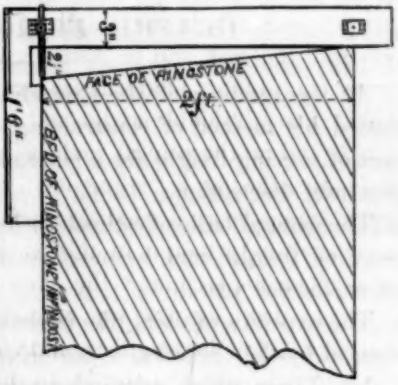
As the curved portion of the approach was finished on top with a finely cut granite coping set on a regular curve, the ringstones had to be laid on the centres to fit this vertical curve, with its radii of 197 ft.

and 142 ft. respectively. The versed sine, or the horizontal distance between the extreme point in the horizontal curve of the arch face at the *crown*, and a chord line drawn at the *spring* of the arch, was at the segmental end 9 in., and at the other end 5 in. nearly.

All the granite work in these arches, except that used in the piers, was cut at the quarries in Maine, and to avoid the necessity of making and shipping a zinc pattern to conform to each face angle in the two sets of ringstones required, the following plan of giving these angles was devised. It was simple and worked well in practice.

An ordinary stone-cutter's square of iron was provided with a sliding graduated bar, and a set-screw as shown at Fig. 3. A separate bar with its proper graduations stamped and numbered upon it was provided for the two ends of the arch, there being 43 ringstones in the segmental arch and only 35 in the full centred arch. When used, the bar was placed at the *top* of the square when the face angle decreased from a right angle, and at the *bottom* when this angle was more than 90°. As each stone was cut it had a number and a letter painted upon, denoting its position in the arch, so that they were readily put in place. We should add that as the angles varied uniformly, a length on the bar equal to the tangent of the angle of greatest variation, from a perpendicular to the bed of the stone, with a radius of two feet, was divided into as many parts as there were ringstones between the springing line and the key. The ringstones were rock face with $1\frac{1}{2}''$ draft, and the offset between any two adjoining ringstones was so slight that no attempt was made to conform to the winding face surface that theory required. The "pointing" was so managed as to hide the slight variation that did exist. The bed of the ringstone was first cut to a zinc pattern, then the build, and finally the face angle obtained with the square as above described.

Fig. 3.



The haunching of the arches was built of well-bedded lime stone from the Conshohocken quarries, laid dry, and thoroughly grouted,

with one part Rosendale cement to two parts of sharp sand, at every 2½ ft. in height. The foundations were of the same stone, laid in cement mortar.

From the foregoing description it will be seen that strict theory was in all cases sacrificed, whenever it could be done without injury to the stability of the work, and much money was saved thereby. The final result was a piece of arched work that has stood perfectly in all its parts, and while possessing many advantages in appearance, really cost less than the more clumsy form, often adopted in similar cases.

GRAPHIC FREIGHT DIAGRAMS.

At the meeting of the Franklin Institute, Mr. P. H. Dudley presented his method of constructing diagrams showing graphically the cost of moving freight for a particular railroad, of which the following is a brief description:

The general basis of estimate being the cost of moving the entire tonnage of freight cars, locomotives and cabooses, of the freight department, for one year.

The expenses of doing the business of a railroad were considered as formed by the operation of two distinct principles, viz.:

1st. Those which were independent of the volume of business done, such as expense of organization for a prospective business, interest on debts, taxes and the general depreciation of the plant by natural causes, which were termed permanent operating expenses.

2d. Those which were dependent upon the amount of business done, such as fuel, repairs to plant due to service and increased help, which were termed direct operating expenses. Owing to differences in organization and method of doing business, each railroad will vary in some of the details of classification.

The various expenses per ton per mile, so classified, were plotted on cross section paper, the abscissæ or horizontal lines representing the tonnage, and the ordinates or vertical lines the cost in dollars and cents, each noted per car. Taking the direct operating expenses per ton per mile, and plotting the results, the ordinates increase regularly; drawing a line through them it rises obliquely from the axis. Now, plotting the sum of the average permanent and direct operating expenses per ton per mile, and also a rate per ton per mile, we have

a means of comparing the rate with the cost per ton per mile. When the plotted rate line falls entirely below the direct operating expenses for the usual length of train, then all business is done at a loss, consequently the greater the volume the greater the loss. When the rate line is below the two expense lines, then the excess above the direct operating expense line tends to reduce the permanent operating expenses (which must be entirely overcome before any net earnings are made). In this case, the greater the volume of business the less the loss. Any special business which gives a rate over the direct operating expenses should be considered. When the plotted rate goes above the sum of both expense lines, the excess shows the net earning per ton per mile, based upon a like volume of business. If the volume has increased, the permanent operating expenses will be decreased, but when the volume is decreased the expenses will be increased per ton.

When the cars are to be returned empty, the direct operating expenses of moving both ways must be added together and plotted as for one way. On foreign cars, the car service must be added before comparing with the rate line. The distribution of expenses by the car for trains, gives curved lines showing that within the limit of train lengths, the expense decreases per car. The oblique lines also show the economy of long trains, as each car tends to reduce the cost of moving the tonnage of the locomotive and caboose. Various items of expense are plotted in detail. A difference of $\frac{1}{1000}$ of a cent in the rate will show. Many of the elements of the expenses were determined by the use of the dynograph.

Stability of Verticals.—Mouchez and Gaillot, the astronomers who computed the intra-Mercurial orbits which agreed so closely with harmonic prediction, have turned their attention to the mooted question whether vertical lines are changeable. As a preliminary result, they find that there are extreme differences of nearly a second of arc; that the variations from the mean are greatest in summer and in winter; that they are probably due to temperature, either through influences on the instruments or on astronomical refractions. The researches, which are very delicate, are still in progress at the Paris observatory.—*Comptes Rendus.* C.

Continuous Railway Brakes.—In the course of his experiments with railway brakes, Captain Dingles Dalton has among other things clearly proved that the brake force required to produce the maximum effect varies according to the speed. It must be very great when first applied and then must be reduced as the speed decreases so that skidding may be avoided. He also concluded that this could best be accomplished by utilizing the friction between the brake blocks and the wheels, for regulating the pressure by which that friction was produced. Quite recently he has made some experiments with a new valve design by Mr. Westinghouse, for the purpose for reducing the pressure and set in action by the brake pressure. This valve was found to give very promising results, and to reduce the pressure in accordance with the requirements, except at the last moment before the train was brought to rest, when, in consequence of the discharge aperature being rather too small, the air could not escape from the brake cylinder quite quickly enough to avoid in every case a slight final jerk. In the former experiments the best results could only be obtained by carrying the exact amount of pressure which was required for the speed from which the stop was made, and which in every case had been previously determined; and the pressure was reduced, as the train speed fell by the manipulation of the temporary reducing valve. When the initial pressure was accidentally too high, or when it was not reduced soon enough, skidding was always produced, with corresponding loss of efficiency. In the present experiments, it was found that, however great the initial air-pressure, the new valve would not allow too much force to be exerted against the blocks, so that an initial pressure which in ordinary circumstances would have produced immediate skidding was rendered unable to do so. The diagrams of the brake-block pressure, taken with the valve in use, show exactly the force required at all speeds, or the very point which it was hoped might be determined by the earlier experiments. By the use of this simple contrivance, maintained in action by the friction of one of the brake blocks, more information has been gained in a single day with regard to the amount of brake power which should be applied at any given speed than in the whole of the former experiments, which were continued over nine days. Twelve stops were made by slipping the van from the engine, and the reducing valve was changed several times, so as to be opened by a greater or less amount of friction. The results obtained were as follows:—Speed in miles

per hours, and yards run before stopping—45 and 96; 53 and 171; 55 and 171; 55 and 141; 60 and 171; 60 and 167; 62 and 176; 54 and 227; 55 and 195; 57 and 206; 57 and 223; 60 and 214. The last five stops on the above list were made with the valve so adjusted as to be opened by a brake-block friction which would not produce skidding even on a wet rail, while in all other cases it was so adjusted as to produce the greatest amount of retardation on a dry rail. The action of the valve was such as to render it apparent that its employment in ordinary traffic, when perfected for this purpose, would be of great practical utility. The air was heard to escape continually, and the valve was highly sensitive. If an appliance of this kind, so simple in its construction and so certain in its operation, were attached to every vehicle, and were so set as to open before the adhesion attainable on a wet rail was exceeded, it would become immaterial whether the driver maintained only a certain pressure for a certain speed, or whether he carelessly applied his brake with a high pressure when running at a low speed. The valves, already adjusted for the required amount of retardation, would act of their own accord, and would only allow the proper degree of pressure to be exerted by the brake-blocks. The stops would then always be made within given distances for given rates of speed.—*Iron.*

Telegraphing to Running Trains.—C. M. Gariel describes the successful working of Baillehache's invention for signalling to and from trains in motion, on a part of the line which connects the Champs de Mars with the station at Grenelle. The experiments were so successful that they are likely soon to be repeated on a much larger scale. —*La Nature.* C.

Changes of Spectra.—If a small quantity of mercury is placed in a hydrogen Geissler tube, E. Wiedeman finds that an induction current gives the hydrogen spectrum at ordinary temperature. But if the tube is warmed in an air-bath, as the temperature rises the mercury lines appear, while the hydrogen lines grow fainter and finally disappear. If a tube of hydrogen and nitrogen is warmed at any point, so as to free sodium or other metals from the glass, the hydrogen and nitrogen lines vanish almost entirely while the lines of the metal appear. Does the hydrogen disappear, or is it transmuted into some other substance?—*Comptes Rendus.* C.

American Bridge-building.—In an address upon the public works of the United States, M. Malezieux compliments the American engineers upon their skill in building bridges of large span, and says that all other nations may borrow many useful hints from them in regard to the use of compressed air in laying foundations.—*Ann. des Ponts et Chauss.* C.

Interesting Experiment.—On the 4th of August, Pasteur enclosed some vine-sets in hot-beds, almost hermetically sealed. The grapes ripened about Oct. 10th. Grapes that had ripened in the open air fermented in less than 48 hours, in a temperature varying between 25° and 30° (77° to 86°F.), but those that ripened under glass remained unchanged. This result, which had been predicted by Pasteur, lends strong confirmation to his views.—*Comptes Rendus.* C.

Japanese Coal Beds.—The Japanese government has offered a liberal subvention for the development of the coal basin in the island of Yesso, where the supply is said to be sufficient to furnish, for a thousand years, as much as is now mined in Great Britain. The apprehension, which is already felt from the competition of the Mongolian races, will be still more reasonable when they have felt the full use of the principal element of European industrial wealth.—*Les Mondes.* C.

Delicate Measurements of Contacts.—C. M. Goulier states that if the eye is so placed as to see the ivory point of a Fortin barometer in the same direction as the image of the cap which the mercury reflects, while the rest of the surface reflects the sky, the naked eye can readily distinguish the slightest indentation of the point into the mercury. By experiments with a vertical micrometric vise, he found that he could estimate the contacts within less than $\frac{1}{3000}$ of a millimeter (·00013 in.).—*Comptes Rendus.* C.

Ancient Milanese Aqueducts.—In making excavations for a new system of sewerage, E. Bignami Sormani has found well-preserved remains of two ancient aqueducts, which were evidently used for conveying fresh water, probably for the supply of fountains and other domestic uses in early palaces or villas. The pipes are of terra-cotta, and Sormani is inclined to refer them to the time of the Roman Empire, the form, mode of construction and general details being indicative of a great antiquity.—*Il Politecnico.* C.

Soluble Glass in Bronzing.—Böttger varnishes objects of wood, porcelain, glass or metal with soluble glass and then shakes bronze powder over them.—*Dingler's Journal.* C.

Bleaching Diamonds.—Ch. Riballier recommends heating grey or brown diamonds with carbonate of lime and powdered coal in air-tight crucibles, and allowing them to cool slowly.—*Ding. Jour.* C.

Rotating Steam-Engine.—A. Müller, of Cologne, connects a number of turbines in a common casing, the diameter of the turbines gradually increasing. The steam enters the smallest and escapes from the largest. This contrivance is said to be very economical either for steam or under a head of water.—*Dingler's Journal.* C.

Retention of Heat.—M. Degremont glues upon cloth a series of small segments or rods of wood to form a sheathing for steam pipes. It has the advantage of being easily removed and replaced, which is not the case with most heat retainers. Small, round-headed nails are used to prevent contact between the wood and the pipe, and to enclose a layer of air between the pipe and the sheathing.—*Bull. de la Soc. d'Encour.* C.

A New Element.—Marc Delafontaine announces the discovery of the oxide of a new metal, to which he gives the name of Philippium [Pp.] in honor of his benefactor, Phillipe Plantamour, of Geneva, the friend and pupil of Berzelius. He is pursuing a comparative study of the compounds of Philippium and of Terbium, and he proposes soon to publish a memoir in which he will describe the processes of preparation and purification.—*Comptes Rendus.* C.

A Silver Mill in the Clouds.—The largest and best arranged silver mill ever made has been lately built by the Pacific Iron Works, of San Francisco, for the Cerro de Paseo Mining Company, in Peru. It has 80 stamps, weighing 900 lbs. each; 44 five-foot amalgam-pans; 22 nine-foot reservoirs, with all the belongings of the newest and best kind. It is made in sections, with no single piece heavier than 500 lbs., because it must be carried by mules over very steep paths, about 150 miles east of Lima, to a height of more than 14,000 feet. There are 17,000 pieces altogether, having an aggregate weight of over 600 tons. The whole mill was built and shipped inside of fifty days. The Cerro de Paseo mines are the richest and most famous in the world, having already yielded more than $500,000,000 worth of silver.—*Der Techniker.* C.

Large Steam-Pump.—Pittsburgh has the largest steam-pump in the world. It weighs 1500 tons, cost $423,350, and pumps 14,240,000 gallons of water per day. Those next in size are one at the Lehigh Zinc Mines, with a service of 3,450,000 gallons, and the two Chicago pumps, with a service of 4,500,000 gallons.—*Der Techniker.* C.

The Microphone as a Thief-Catcher.—An Englishman in India, finding that his oil disappeared with wonderful rapidity, attached a microphone to the can, with a wire leading to his bed chamber. Soon after he had closed the house for the night, he heard a gurgling noise, and, running quickly down stairs, he caught the thief in the act of filling his own flask from the can.—*Der Techniker.* C.

High Trees.—The highest sequoia tree in the United States is in Calaveras grove, near Stockton, California. It is 325 feet high. A eucalyptus was once felled in Australia which was 500 feet high, with a circumference of only nine feet. Near Fernshaw, in the Danderong District, Victoria, an "almond-leaf gum" (*eucalyptus amygdalesius*) has lately been found which measures 380 feet from the ground to the first branches and 450 feet to its top, thus exceeding the California tree by 125 feet.—*Der Techniker.* C.

Constitution of Nebúlæ.—In the "Investigations upon the height of the atmosphere and the constitution of gasiform cosmical bodies," A. Ritter deduces the following law: "If, in consequence of increase or diminution of heat, the radius of the gaseous globe undergoes a change, the temperature of its centre also changes; but the product of the radius into the central temperature is constant." If p, v, T, respectively, designate the pressure, specific volume and absolute temperature of a definite, minute portion of the body, $pv^{\frac{4}{3}}=$ constant; $Tv^{\frac{1}{3}}=$constant; $\frac{T^4}{p}=$constant. Since Neptune's orbital radius is about 6,000 times as great as sun's present radius, according to the above law the sun's central temperature is now about 6,000 times as great as when, according to the Kant-Laplace hypothesis, the sun was expanded to the orbit of Neptune. Of the whole work which has been performed by gravity during that immense interval, more than four-fifths is still stored within the sun's mass in the form of heat.—*Ann. der Phys. u. Chem.* C.

Purification of Fatty Waters.—Prof. F. Hetet has described his automatic apparatus for the purification of fatty waters by lime water both for the purification of boilers and for making distilled water drinkable. The French Navy Department has adopted his method for all boilers with surface condensers.—*Bull. de la Soc. d'Encour.* C.

Parallel Pincers.—Robert Muencke, in *Dingler's Journal* (1878, 230, 36), describes a useful contrivance for holding retorts, alembics, tubes, etc., in chemical laboratories. They are made on the principle of the parallel vise. Their close grip and the various uses to which they may be applied will doubtless give them a wide popularity. C.

Harbor of Alexandria.—Alexandria has the largest artificial harbor in the world. The outer breakwater is two miles long; a tongue of land curves around the harbor, so that there is no exposure to the winds and waves, except the straight and deep canal which serves as an entrance. The solidity of the breakwater, quays and jetties does great credit to the contractors, who finished the whole in eight years.—*Les Mondes.* C.

Stability of Molecular Systems.—In discussing the constitution of matter, Wurtz describes the various movements of vibration, rotation, gliding, rectilinear progression and orbital revolution, to which the atoms and molecules of all bodies, solid, liquid and gaseous are continually subjected. To the question whether all these varied and continual motions are not sources of instability, he answers: Quite the reverse. If the atomic aggregations were immovable, they would be more unstable than they are while moving; the familiar example of the bicycle illustrates the influence of motion on the stability of equilibrium.—*Bib. Sci. Internat.* C.

Allotropy of Metals.—M. Schützenberger, in his investigations of the different molecular states of metals, finds that other metals than antimony, especially copper, lead and silver, take allotropic forms when precipitated from saline solutions, by electrolysis or otherwise. He predicts that this will prove to be the case with a large majority of metals. The less active and more stable modification is formed at the expense of the other, with loss of heat, like red phosphorus from ordinary phosphorus, or oxygen from ozone. Allotropic copper, when oxydizing in the air, takes brilliant rainbow hues, which may have a valuable industrial application.—*Bull. de la Soc. d'Encour.* C.

Interpretation of Imaginary Roots.—M. Appell shows that, in some cases, the imaginary roots of time-equations, in mechanics, represent a simple reversal of the direction of the constant force.—*Comptes Rendus.* C.

Renewal of Files.—The application of Tilghman's sand-blast to the restoration of worn-out files is becoming very general in Europe. A file of moderate dimensions requires only three or four minutes for renovating. The process can be repeated many times before the files need to be recut, and the sand-blast sharpening lasts six times as long as any other. The sand should be very fine and driven with great velocity.—*La Gaceta Industrial.* C.

Early Snow.—"The oldest inhabitant" of Vienna does not remember so heavy a snow-fall in the early part of November, as that of the present season. The squall began soon after midnight and continued through the whole day of Nov. 3. By 11 A. M. it was almost impossible to move in the streets. In the public gardens, at the Prater and on the Ring, the havoc was fearful, and many of the beautiful trees of the Ringstrasse were seriously injured. Many of the cast iron telegraph poles were thrown down, and one of them killed a passer-by. Telegraph wires were broken, and on some of the lines communication was interrupted for several days.—*Les Mondes.* C.

Electro-Chemical Action Under Pressure.—In a series of about 50 experiments, each of which continued for several hours, and during which pressures of 100, 200, 300, etc., atmospheres were maintained, A. Bouvet found the following laws: 1. The decomposition of water by a current is independent of its pressure. 2. The quantity of electricity necessary to decompose a given weight of water is sensibly the same, whatever may be the pressure. The laws are in perfect accordance with the mechanical theory of heat, the work being represented by the formula:

$$T = P V \int \frac{dv}{v} = P V \text{ log. hyp. } \frac{V_1}{V}$$

T, work; V_1, final volume; V, volume of compressed gas; P, pressure. Bouvet claims to have pointed out the principles of Cailletet and Pictet, in a memoir addressed to the French Academy Oct. 8, 1877.—*Comptes Rendus.* C.

Registering Electrometer.—The quantities of atmospheric electricity and terrestrial magnetism are so minute that they have hitherto been measured by delicate apparatus and recorded by photography, a process which is very costly and often unsatisfactory. Mascart has invented a mechanical register, to accompany Sir Wm. Thomson's electrometer, which gives admirable results. It can be connected with various other instruments.—*La Nature.* C.

Gypsum in Cement.—During the past decade, the use of Gypsum for the improvement of ill-burnt Portland cement has attracted some attention. F. Schott gives the following results of experiments:

		Tenacity, after 7 days	
	Weight.	Air.	Water.
Pure cement,	100	10·5	8
" " with 1 p. ct. unburnt gypsum,	115	14·0	—
" " " 3 " " "	120	18·0	10
" " " 1 " dead burnt "	112	11·0	—
" " " 3 " " "	113	12·5	—
" " " 3 parts sand,	—	8·0	6
" " " 3 " " &3 p.ct.u.b.gyp.	—	13·0	7

—*Dingler's Journal.* C.

Spectral Investigations.—E. Wiedemann has studied the spectrum of mixed gases, especially in Geissler tubes, with a view to extending the theory of spectral lines and bands. The rotary and oscillatory movements of the atoms and molecules appear to produce periodical vibrations in the surrounding luminiferous æther, and the harmonic arrangements which have been pointed out in the lines of many of the chemical elements are probably due to those vibrations. The transfer of electricity from particle to particle differs in different substances, so that only certain portions are illumined by the mere passage of the spark. This fact, together with some phenomena of fluorescence, serves to prove that the oscillations of the æthereal envelopes can be exerted without increasing the living power of all the particles, as would be necessary according to the Kinetic theory of gases. In order to test this hypothesis, Wiedemann has begun a series of experiments in which the temperatures of the discharges in Geissler tubes will be determined under various circumstances.—*Ann. der Phys. u. Chem.* C.

Swiss Coal.—Switzerland has hitherto been obliged to import all its coal, but a bed has been lately discovered at Sonnenberg, near Luzerne. It is in the oldest tertiary, and contains two veins of about 3000 metres (1·864 miles) in length. It is of excellent quality, and the beds are thick enough to be favorably worked, averaging about 1 metre (39·37 inches). Four galleries have been opened already, and a fifth is under way.—*Les Mondes.* C.

The Earth Speaks.—In June last, Palmieri first observed that the seismograph, with the aid of a transmitting microphone and a receiving telephone, enables the ear to hear the vibrations of the ground. Rossi subsequently experimented with a more delicate apparatus, and at each manifestation of the volcanic eruption he heard the same sounds in the agitated soil. The two professors have repeated their observations at Pozzuoli and Solfatara, with the same results.—*Roma.* C.

Ytterbium.—In continuing his analysis of *gadolinite*, Marignac finds that Erbium contains two distinct oxides. One is of a pure rose color, with a very characteristic absorption-spectrum; the other is white, its salts are colorless, its nitrate is decomposed by heat without coloration, its solutions show no absorption rays, it is not easily attacked by acids, and its equivalent is relatively high. He proposes that the first shall retain the name of Erbium, and the latter shall be called Ytterbium.—*Comptes Rendus.* C.

Electrization of Plants.—On July 30, 1877, M. Celi planted three kernels of maize under each of two bell-glasses. The weight of the kernels, the kind of earth, and the quantity of water supplied daily, were equalized as nearly as possible. On Aug. 1, the kernels sprouted. During two days the growth was nearly the same, under both glasses. On the third day the plants in electrized air began to develop more rapidly than the other. On Aug. 10 the following measurements were taken, from the base of the stalk to the extremity of the upper leaves:

Plants in electrized air,	. .	17 cm. (6·69 in.)
" " ordinary "	. .	8 " (3·15 in.)

—*Comptes Rendus.* C.

Decipium.—In continuing his researches upon samarskite, Delafontaine reports the discovery of a new metal which he calls *decipium* (from *decipiens*, deceitful). This metal possesses many of the properties which are common to cerite and gadolinite. He believes its color to be white, although he has not yet separated it sufficiently from didymium to be positive on this point. Its salts are colorless by themselves; the acetate crystallizes very readily and appears to be less soluble than that of didymium but more so than that of terbium.—*Comptes Rendus.* C.

American Cartridges.—The Americans excel all other nations in the quality of their cartridges. The superiority is due in part to the alloys which they use, in part to the machinery, and in part to the skill of the workmen. The Russian, French, German and Turkish Governments have sent official experts to study the American methods and intelligent mechanics to work in the American factories as journeymen. But the result has not been satisfactory; although using the same processes, the cartridges which they have made are of inferior quality.—*La Gaceta Industrial.*

Bridge over the Douro.—The *Maria-Pia* bridge, built by Eiffel, of Paris, has a central bay of 160 meters (174·98 yards) span, the longest yet built for any but suspension bridges. The other chief spans are the Britannia bridge, 140 meters; bridge of Kuilembourg, 150 m.; St. Louis bridge, 158·5 m. Work was begun in Jan., 1876, and finished Oct. 31, 1877. The weight of iron is 1450 tonnes (3,196,700 lbs.), of which 750 tonnes are for the arch and 700 for the roadway and piles. The amount of masonry is 4000 cubic metres (5232·086 cubic yards).—*La Nature.* C.

Electricity of Chemical Processes.—F. Braun finds that the percentage of potential energy convertible into mechanical work, varies inversely with the electric tension; a sudden change in the density of free electricity must be accompanied by a development of heat even if it is not followed by any change of relative distribution; if induction-currents in a spiral excite a maximum of free electricity, half of the work is converted into heat; in currents of small intensity, if a new current is added, a greater development of heat and a less degree of polarization arise when the new current is in the same direction as the original current than when the directions are opposite.—*Ann. der Phys. u. Chem.* C.

Chanoit Filter.—A metallic reservoir is supplied by a pipe entering at the bottom. The water is forced by the pressure of a hydrant, or of a head, upward through the filtering bed, compressing the air before it, and thus becoming thoroughly aerated. The filter can be readily cleaned by opening a discharging cock in the bottom. Faucets for drawing the filtered water, or for conveying it to other rooms, are inserted above the bed.—*La Nature.* C.

Greek Bread.—The ancient Greeks used covered terra-cotta utensils, called *cribanoi*, which were pierced with holes in their circumference, and which were the prototypes of the modern "Dutch ovens." After the dough was put in they were surrounded by burning coals, and the heat, penetrating by the holes, gave a more uniform temperature than an ordinary oven. After the reign of Pericles, Athens became renowned for the skill of its bakers and its cooks. They made twenty or more kinds of bread, some of which were very white and of excellent flavor. Plato reports that, a century before his time, a Sicilian baker, named Thearion, had made great improvements in his art. The Cappadocians made a very delicate bread, like Vienna rolls, by adding to the wheat flour a little milk, oil and salt.—*La Nature.* C.

Werdermann's Electric Light.—The principle is much like Reynier's. A slender carbon moves in a metallic tube, which serves both as cylinder and as conductor of the current. A collar on the lower portion connects it by cords to a counterpoise, which tends to raise the carbon and keep it lightly pressed against a carbon disc, two inches in diameter, kept in a fixed position by a vertical support, and connected with the negative pole. The incandescence is limited to the portion of the positive margin (about $\frac{3}{4}$ inch) between the metallic tube and the negative disc. A gramme machine, driven by an engine of two horse-power gave the following results: 1. When the current was distributed between two lamps, it gave a light of 360 candles, white and perfectly steady. 2. When divided between ten lamps, each focus represented about 40 candles, and the total resistance of the circuit was only 0·037 ohms. 3. The disc, on account of its great mass, does not burn or undergo any change. The crayons consume less than 3 inches per hour for large lamps. All the lamps can be lighted or extinguished either at once or successively.—*Comptes Rendus.* C.

Electrophone.—C. Ader uses a sort of drum, having on one side a diaphragm of parchment paper, about 15 cm. (5·91 in.) in diameter, in the centre of which are circularly arranged six bits of tinned iron, 1 cm. (·374 in.) long, and 2 mm. (·079 in.) wide. Upon these act six microscopic horse-shoe electro-magnets, which are connected and set in action by a carbon-speaking microphone. A Leclanché pile of three elements transmits words and music so that conversation can be heard 5 meters (16·4 ft.) from the instrument. The energetic efforts are due to the minuteness of the electro-magnets, which can be magnetized and demagnetized much more rapidly than in other systems.—*Comptes Rendus.* C.

Magnetism of Loadstone and of Steel.—Dr. A. L. Holz has investigated the comparative influences of equal amounts of magnetism upon the loadstone and upon glass-hardened steel. He has reached some novel conclusions, among which are the following: 1. The maximum of permanent magnetism in the loadstone, for equal volumes, is about the same as that in the hard steel. 2. The specific magnetism of the loadstone is the greatest of all magnetic bodies yet investigated. 3. The permanent magnetism of the loadstone is sooner reached than that of steel. 4. The quantity of temporary magnetism which disappears, after the magnetizing force is removed, is less in the loadstone than in steel.—*Ann. der Phys. u. Chem.* C.

Spontaneous Combustion.—E. Bing, of Riga, has experimented with different materials; wadding, raw flax, hemp, the waste from silk, wool and cotton spinning as well as sponge, and finally wood dust as found in any cabinet-maker's shop. They were saturated with various fluids, viz., oils, fresh and in a gummy state; turpentine, petroleum, various varnishes, etc.

All the fibrous materials took fire when saturated with any of these oils or with mixtures of the same. Sponge and wood dust, on the contrary, proved to be entirely harmless.

Combustion ensued most rapidly with 17 g. of wadding and 67 g. of a strong oil varnish, in 34 minutes; while 200 g. of washed cotton waste, of which a portion was saturated with 750 g. of strong oil varnish and the remainder wrapped about it, required almost 14 hours. These materials were placed in a well-sheltered spot and subjected to a heat of from 18° to 40° (C.)

Silk did not flame up, but slowly charred. Small quantities seem to take fire sooner than large.—*Wochenschrift des Ver. deutsch. Ing.* P.

A THIRD VERIFICATION OF PREDICTION.

Editors JOURNAL FRANKLIN INSTITUTE:

Gentlemen:—Th. von Oppolzer (*Comptes Rendus*, Jan. 6, 1879) gives elements, deduced from eight supposed planetary sun-spots, which represent another of my harmonic positions:

	Dist.	Time.
Von Oppolzer, ...	·123	15·8 days.
Chase, predicted, . .	·120	15·1 "

This leaves only one still "missing link" in the principal harmonic series, between the nearest fixed stars and the sun. There are many secondary or possible asteroidal positions, between Mercury and the Sun, one of which has been filled already by Mouchez's second Watson orbit. Yours truly,

PLINY E. CHASE.

HAVERFORD COLLEGE,
February 10th, 1879.

Book Notices.

THE RELATIVE PROPORTIONS OF THE STEAM ENGINE. By Wm. D. Marks, Whitney Professor of Dynamical Engineering, University of Pennsylvania. Small 8vo, pp. 161. J. B. Lippincott & Co., Philadelphia, 1879.

This is a course of lectures on the steam engine, delivered to the students of dynamical engineering in the University of Pennsylvania, in which the author has reduced all the required dimensions to functions of the steam pressures, length and number of strokes and horse-power.

While accepting the great value of the writings of Zenner, Poncelet, Huss, Reuleaux and others upon the subject, covering thoroughly the principle of the steam engine, and treating fully some of its members, the author felt that a practical method of determining the proper relative proportion of all parts of the steam engine, was still a desideratum in the English literature of the subject. He has drawn largely from

standard writers upon points already well established, while he has studied fully those which have not received the attention they deserve.

The book is clearly printed on tinted paper, and well indexed.

We are informed that this work has been adopted as a text-book in the Sheffield Scientific School, Lehigh University and the University of California.

Franklin Institute.

HALL OF THE INSTITUTE, Feb. 19th, 1879.

The stated meeting was called to order at 8 o'clock P. M., the President, Mr. W. P. Tatham, in the chair.

There were present 157 members and 47 visitors.

The minutes of the last meeting were read and approved.

The Actuary presented the minutes of the Board of Managers and reported that at the last meeting 3 persons were elected members of the Institute, and that there was a vacancy in the Board caused by the election of Mr. Tatham to the Presidency.

The Committee on the Library reported the following donations:

First to Fifth Annual Reports of the Water Board of the City of Lowell to the City Council, January 1, 1874, to January 1, 1878.
From the Lowell Water Board.

Eighth, Thirteenth, Fourteenth and Fifteenth Reports of the Board and First and Second Reports of the Department of Public Works of Chicago. Chicago, 1869, 1874, 1875—1878.
From D. S. Mead, Secretary.

United States Geological Exploration of the Fortieth Parallel. C. King, Geol. in Charge. Vol. 1. Systematic Geology. Washington, 1878. From the Chief of Engineers.

Steel plate Portrait of John Sartain. From C. Lartenbacker.

Specifications and Drawings of Patents for August, 1878.
From the Commissioner of Patents, Washington.

Fourteenth to Nineteenth and Twenty-first Annual Reports of the Board of Trustees of the Water Works of Cleveland, 1869—1874 and 1876. From the Board.

Annual Report of the Comptroller of the Currency to Third Session of Forty-fifth Congress of the United States. Dec. 2, 1878.
From J. J. Knox, Comptroller, Washington.

Transactions of the Royal Irish Academy. Vol. 26, Science, Parts 6—16, and Vol. 27, Polite Literature and Antiquities, Part 1; Proceedings, Vol. 1, No, 12; Vol. 2, No. 7, and Vol. 3, No. 1.
From the Royal Irish Academy, Dublin.

Annual Reports of the Light House Board to the Secretary of the Treasury, for 1867 and 1869.
From the Treasury Department, through Hon. Chas. O'Neill.

Pennsylvania Archives. Second Series. Charter, 1682.
From the Historical Society of Pennsylvania, Philadelphia.

Polar Colonization. A Memorial to Congress, etc.
From H. W. Howgate, U. S. A.

Researches in Telephony. By Prof. Dolbear. 1878.
From the Author.

Conférence faite au palais du Trocadéro le 7 Aout, 1878. Par M. Malezieux. Paris, 1878. From the Author.

Floral Guide. By J. Vick. Rochester, N. Y., 1878.
From the Author.

Experimental Trials of the Power required to Drive certain Ring Spindles, made by J. B. Francis, Lowell, Mass. From the Author.

Drift from York Harbour, Me. By George Houghton, N. Y.
From the Author.

Reports of Permanent Committee of First International Meteorological Congress at Vienna. London, 1878.
From the Meteorological Committee of Royal Society.

Aeneidea; or Critical, Exegetical and Aesthetical Remarks on the Aeneis. By J. Henry. Vol. 1 (3 parts) and Vol. 2 (1 part). Duplin, 1878. From the Royal Irish Academy.

Geological Survey of Missouri. Reports of State Geologists for 1855—1876. With two Atlases.
From C. P. Williams, Acting Geologist, Philadelphia.

Reports of the Auditor-General of Pennsylvania on the Finances of the State for 1875—1877. From the Auditor-General.

Report of Chief of Ordnance for 1878. Washington, 1879.
From the Chief of Ordnance Bureau.

United States Geological Explorations of Fortieth Parallel. Vol. 5. Botany. C. King, Geologist in Charge.

From the Chief of Engineers.

Brevet d'Invention. Law of 1791. Vols. 48 to 55, 1843–45. Vols. 81 to 93, 1853–63. With Index to Vols. 41—93.—Old Series Law of 1844. Vols. 16 to 47, 1853–64. Vols. 56 to 80, 1864–73 and 85 to 88. With Indexes for Vols. 1—79, in 4 vols.—New Series. Vols. 9 to 13, 1876–78. In 93 vols.

Catalogues des Brevets delivrés du 1er Janvier, 1828, au 31 Dec., 1877. In 36 vols.

From the Minister of Agriculture and Commerce of the Republic of France, Versailles.

Cartes des Voies et Communications de la France. En 6 feuilles.

Cartes des Voies et Communications. En 2 feuilles.

Cartes de la Navigation Interieur.

Carte du Tonnage des Routes Nationales.

Carte du Tonnage de la Navigations.

From the Minister of Public Works of the Republic of France, Versailles.

Mr. John Richards read the paper announced for the evening on Measuring and Gauging Implements.* The subject of the paper was exemplified by a measuring machine of six inches capacity, and believed by the author to be as nearly perfect as any ever built. Also the transfer measuring machine and a large number of gauging and calipering implements.

In the discussion which followed the reading of this paper, Mr. J. W. Nystrom stated the first English standard yard was a brass bar called the parliamentary standard, made by Mr. Bird in the year 1758. About two years later, or in the year 1760, the same maker made another brass bar yard, which was considered the English standard, but not legalized by act of Parliament until the year 1825, when it was termed the imperial standard. Its correct length should be at a temperature of 62° Fahrenheit. Sir George Shuckburgh, who took great interest in correct measures of length, compared the two Bird's standard yards, and found them to differ about $\frac{2}{10000}$ths part of an inch.

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* See page 172.

In the latter part of the last century, Mr. Troughton, of London, was celebrated for having the most correct engines for dividing lengths, and he was, therefore,engaged by Sir Shuckburgh to make a standard yard divided into thirty-six inches with subdivisions, which yard was adopted by scientific men as the highest authority, not so much for its correct length, but principally for its accurate divisions.

Mr. Troughton was then known to have the most delicate apparatuses for comparing standard lengths, and was thereupon engaged by our government to make a standard measure of length for the United States, equal to that of the English. Thus he made a brass scale eighty-two (82) inches long, which was deposited in the Office of Weights and Measures at Washington and adopted by the United States Coast Survey. Its correct length should be at 62° Fahrenheit.

The United States standard yard was taken from this scale, between the 27th and 63d inches. (See Report on Weights and Measures, by A. D. Bache, 1857.)

It has since been found that the standard yard, so obtained, was 0·00005803 longer than the English imperial standard yard. This difference was no doubt due to incorrectness of the divisions on the original scale, or derived from insufficiently delicate appliances for reading off the measure from the English standard.

1t cannot be expected that the divisions on the English scale could be very correct, from want of knowledge in those days to make a correct screw, which is yet a difficult problem, even with our advanced knowledge of mechanic arts.

It was thus originally intended to have the English and American standards of length alike, and we ought not to acknowledge any difference. The Smithsonian Institution published tables in the year 1859, comparing the length of the English and American foot measures, which makes the American yard $\frac{2}{1000}$th parts of an inch longer than the Imperial standard yard, or a difference of four (4) inches per mile.

The United States Coast Survey has now made the American standard yard the same length as the Imperial standard yard.

Mr. P. H. Dudley exhibited and described his system of synchromizing clocks for different longitudes from a central station, and also his method of constructing diagrams, illustrating graphically the lowest rates at which railroads can carry freight.*

*See page 196.

Prof. W. D. Marks described the working of his compound compass for describing arcs of circles up to an infinite radius, all of the conic sections for curves of higher degrees, it being an adaptation of Purcelle's parallel motion; also a linkage of his invention for describing epi- and hypo-cycloids.

The Secretary presented a large astronomical transit and clock, being parts of a set of instruments built by Messrs. Heller & Brightly for the State University of Oregon.

Deacon's waste-water meter, which makes a diagram of the comparative quantity of water passing at any period, by means of which the wastage from leaks, open faucets, etc., in any water-supply system may be detected; Ball's device for making change with coins, consisting of a series of tubes of proper sizes to hold coins of the various denominations, and having at the bottom of each, a slide operated by a lever in such a manner, that when the lever is pressed down, one piece of coin is dropped into a receptacle below. When the coins necessary to make the sum required are all deposited, a slide in the bottom of the receptacle is pushed back by the ends of the fingers in such a manner as to bring the palm of the hand under the opening to receive the coins: Also a new metallic shingle, made of sheet iron cut to a point at one end, and having corrugations which fit into each other and prevent the wind from driving the water under the shingles when laid.

The resolutions of the Board of Managers and of the Committee on Sciences and the Arts relative to the award of medals were called up, when, on motion, the whole subject was laid upon the table.

On motion, the Institute went into the election of one Manager, to serve two years, to fill the vacancy reported from the Board, and the Chair announced that nominations were in order, whereupon Messrs. Henry Cartwright and John J. Weaver were placed in nomination. The Chair appointed Messrs. G. M. Eldridge and C. Chabot, tellers to conduct the election, and after all had voted who wished, the Tellers reported that Mr. Cartwright had received 40 votes and Mr. Weaver 8 votes, whereupon the Chair declared Mr. Cartwright elected to fill the vacancy specified.

The President announced the following standing committees for the current year: